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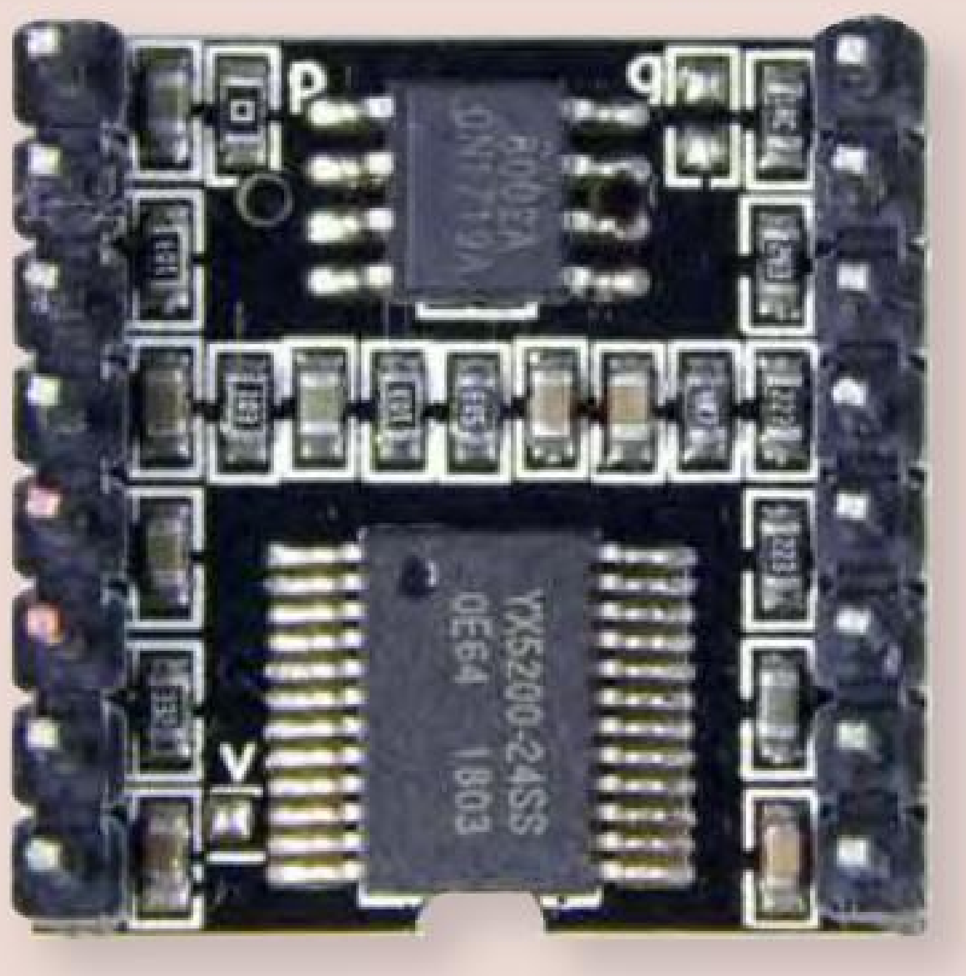

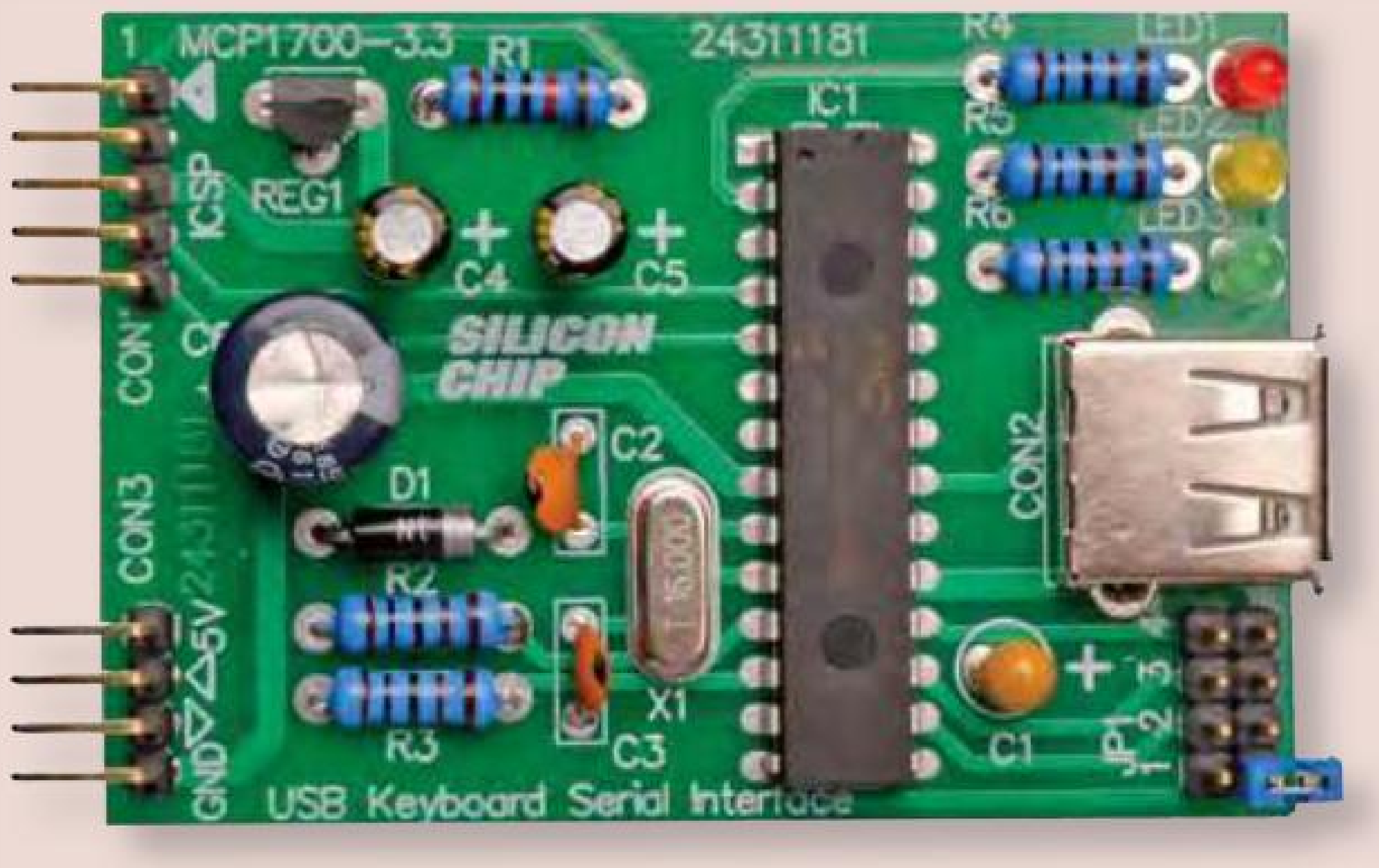

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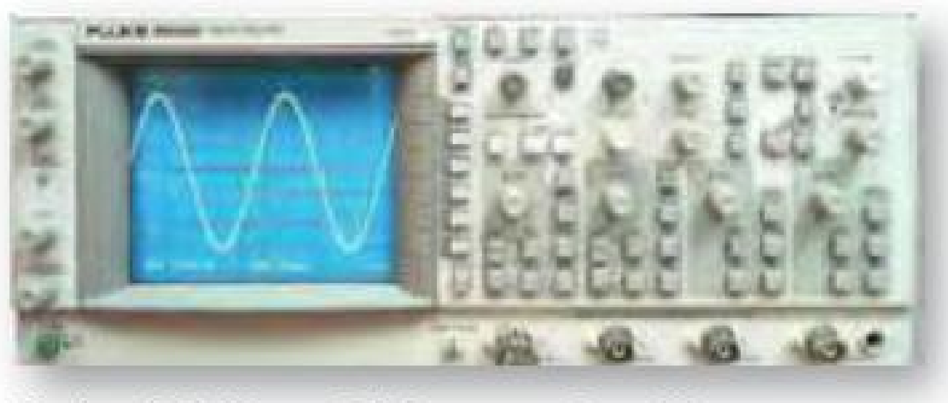

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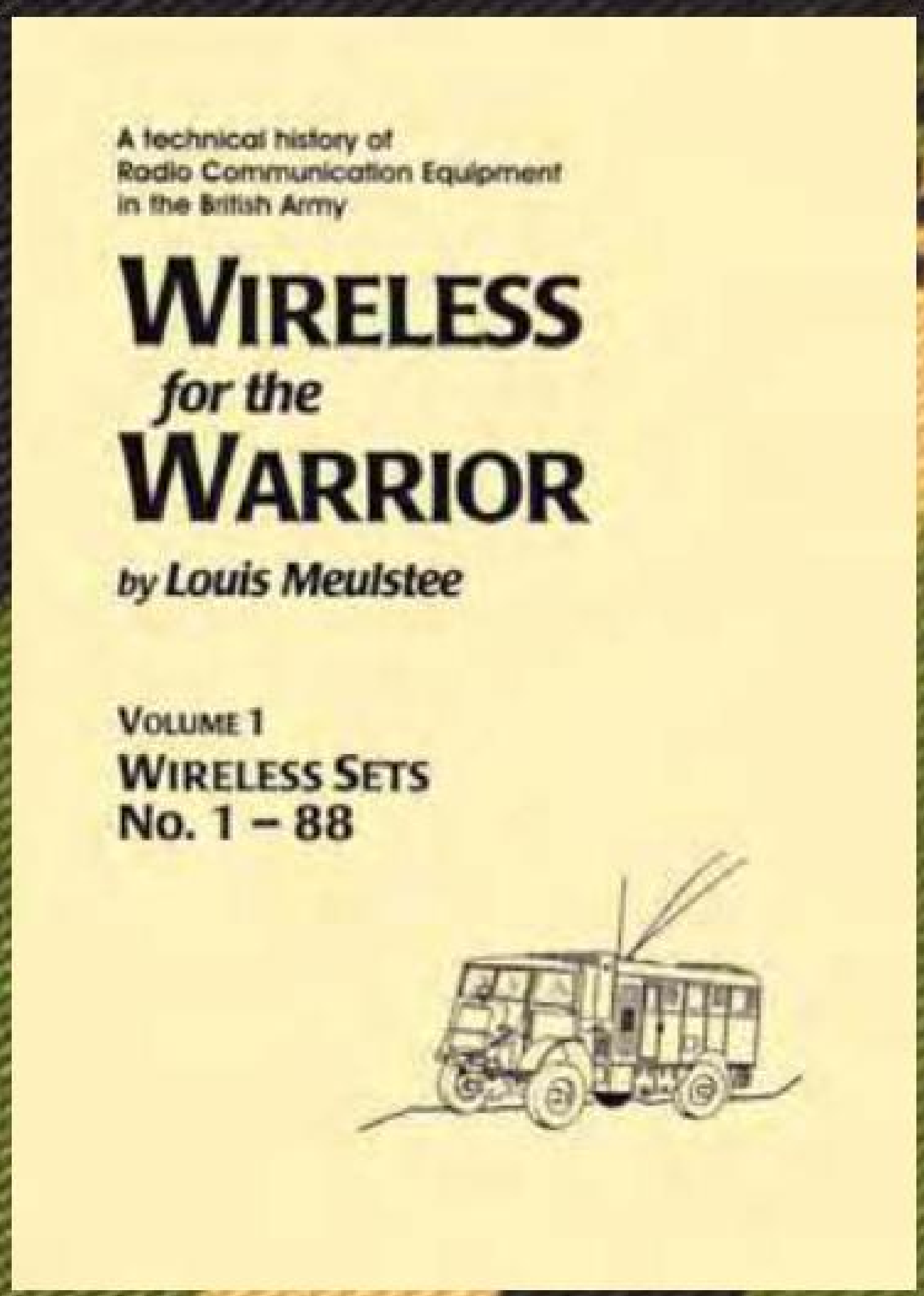

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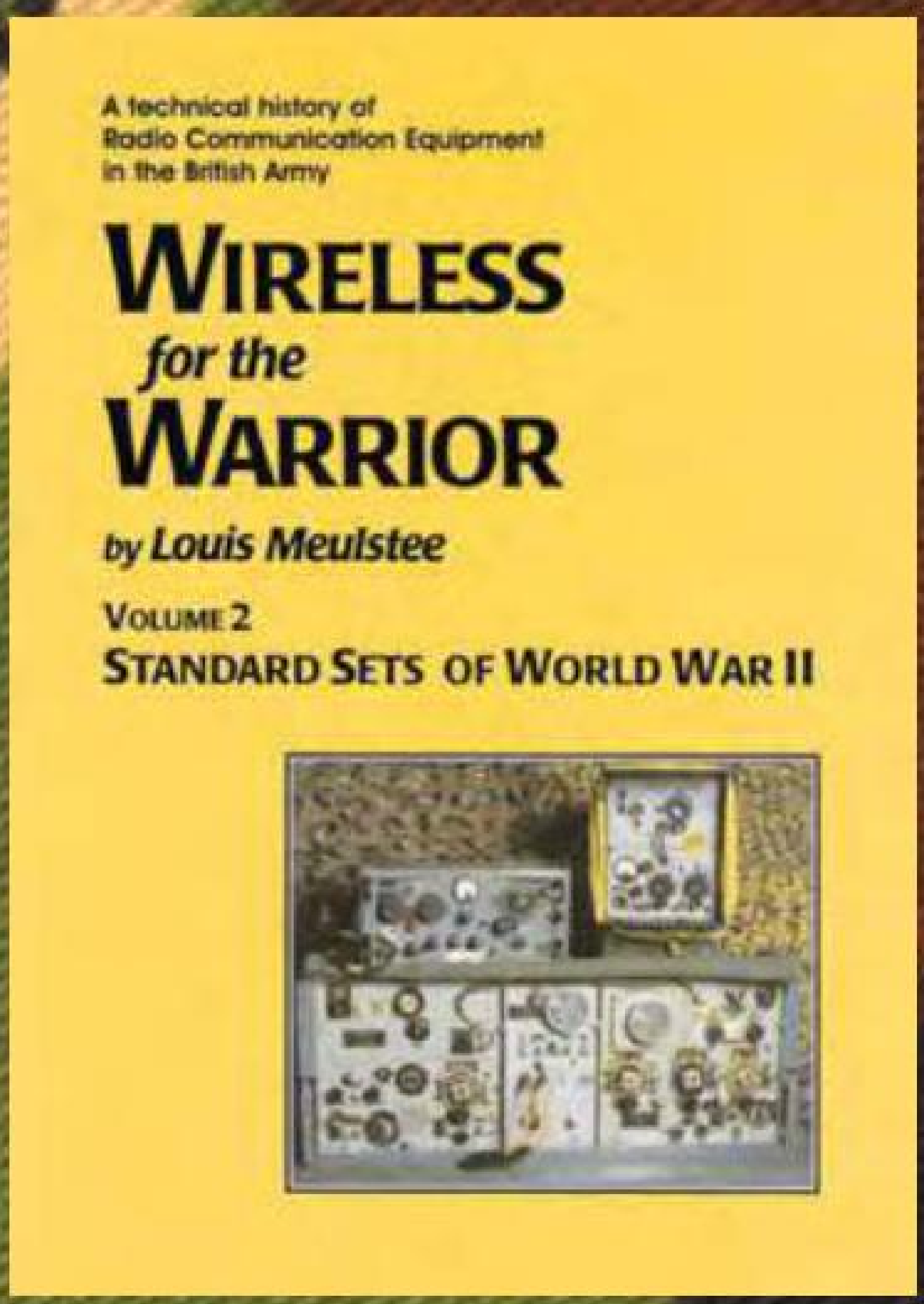

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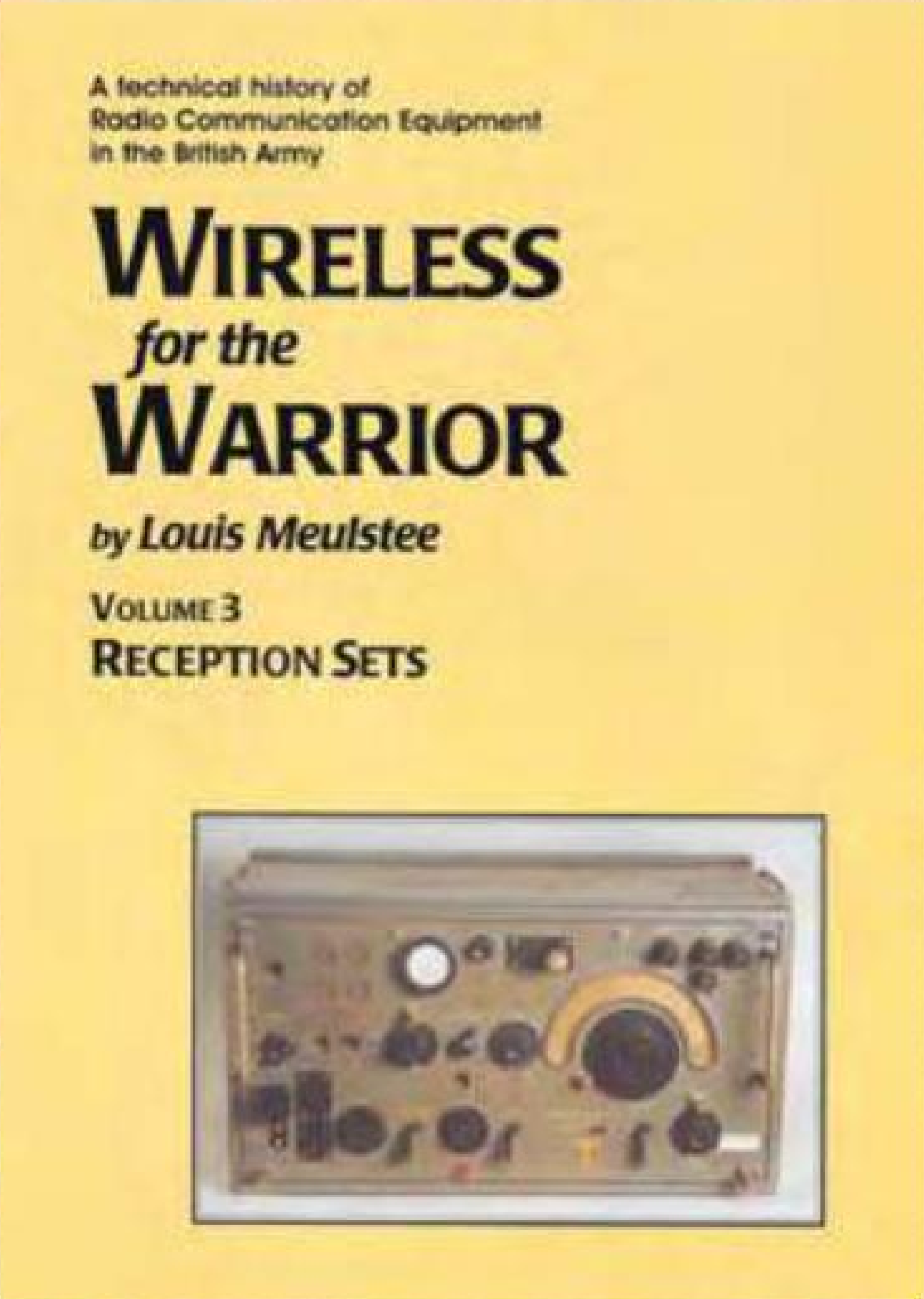

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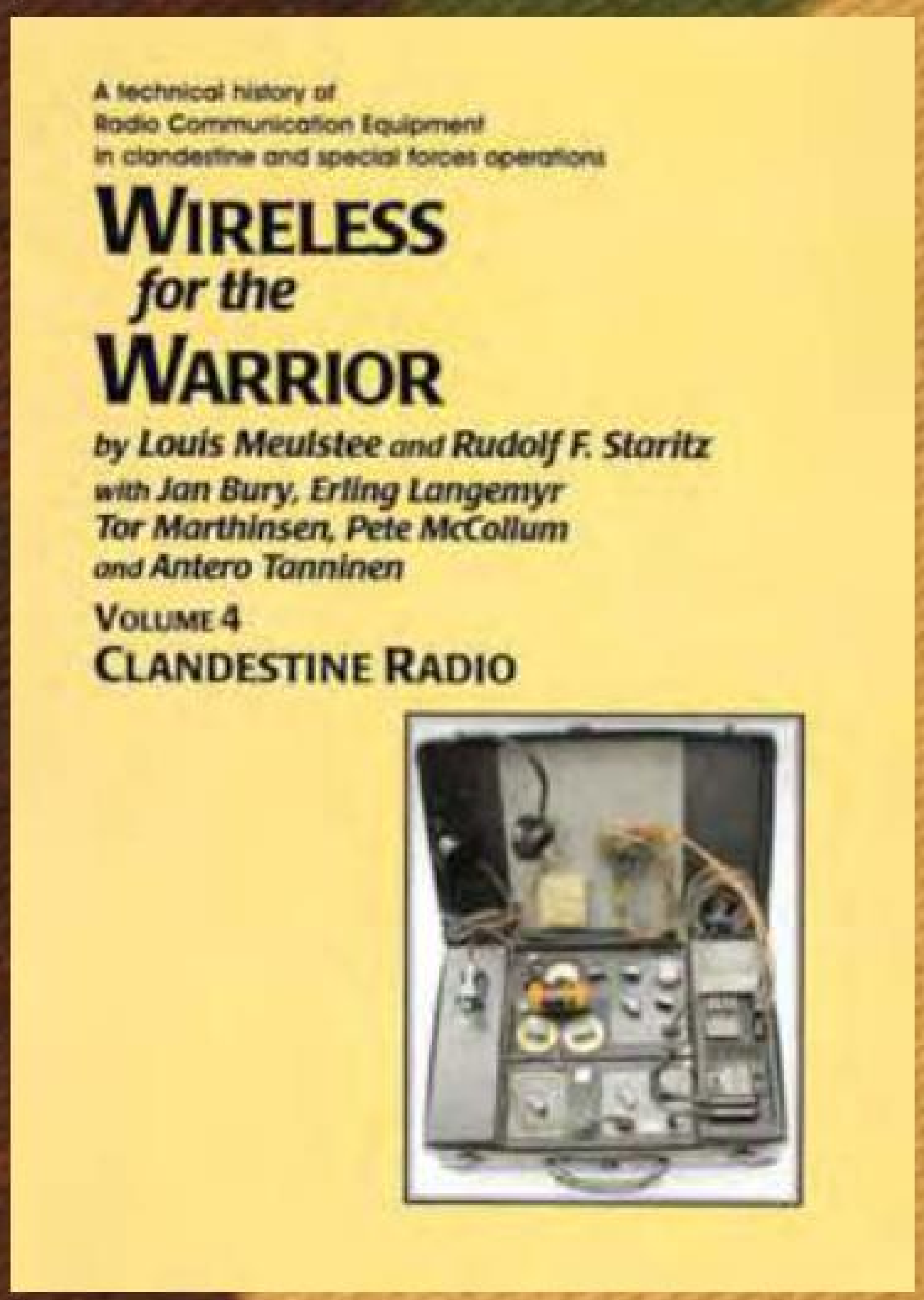

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Happy New Year

Welcome to 2020 and a brand new *Practical Electronics*. I do hope Christmas treated you well and you're all set for a bumper year of unmissable projects and your favourite columns.

This issue sees the second part of a particularly ambitious and interesting project – the *Audio Digital Signal Processor* (DSP). If audio and advanced PICs are your thing, then this really is a must-build. But the fun doesn't stop there, because to some extent this is a misnamed project. It is actually a set of general-purpose building blocks for numerous digital signal processing applications. We will be reusing it for future projects totally unrelated to audio – for example, a DIY reflow soldering oven/PID temperature controller. It's a fascinating collection of DSP circuits – just the project to test you over the long winter nights!

It's launched!

Yes, at long last our new shop is up and running (see this month's *Net Work*). Huge thanks go to our web systems manager, Kris Thain, plus the unstinting support of Alan Winstanley. In many ways a smoothly running web shop is a bit like a sophisticated, but low component component PIC circuit. On the surface there isn't much to see, but under the bonnet a great deal of hard work has gone into the apparent simplicity. Again, thank you Kris and Alan. We've had lot of orders so – I think! – it is basically working well, but do get in touch if you have any problems.

PDF download passwords

One area where we have had a little difficulty is with usernames/passwords for those of you who buy *Practical Electronics* as a downloadable PDF. It is vital to understand that for historical reasons the shop and the download system are entirely separate. Your username/password for one is not the same as for the other. You set up the username/password for the shop, but we issue you with the password for downloads. This is not satisfactory and we are working to change to something seamless – please bear with us just a little longer as we move to a single unified system.

From all of us at *Practical Electronics*, have a great 2020!

Matt Pulzer
Publisher

The Fox Report

Barry Fox's technology column

Good: could be better

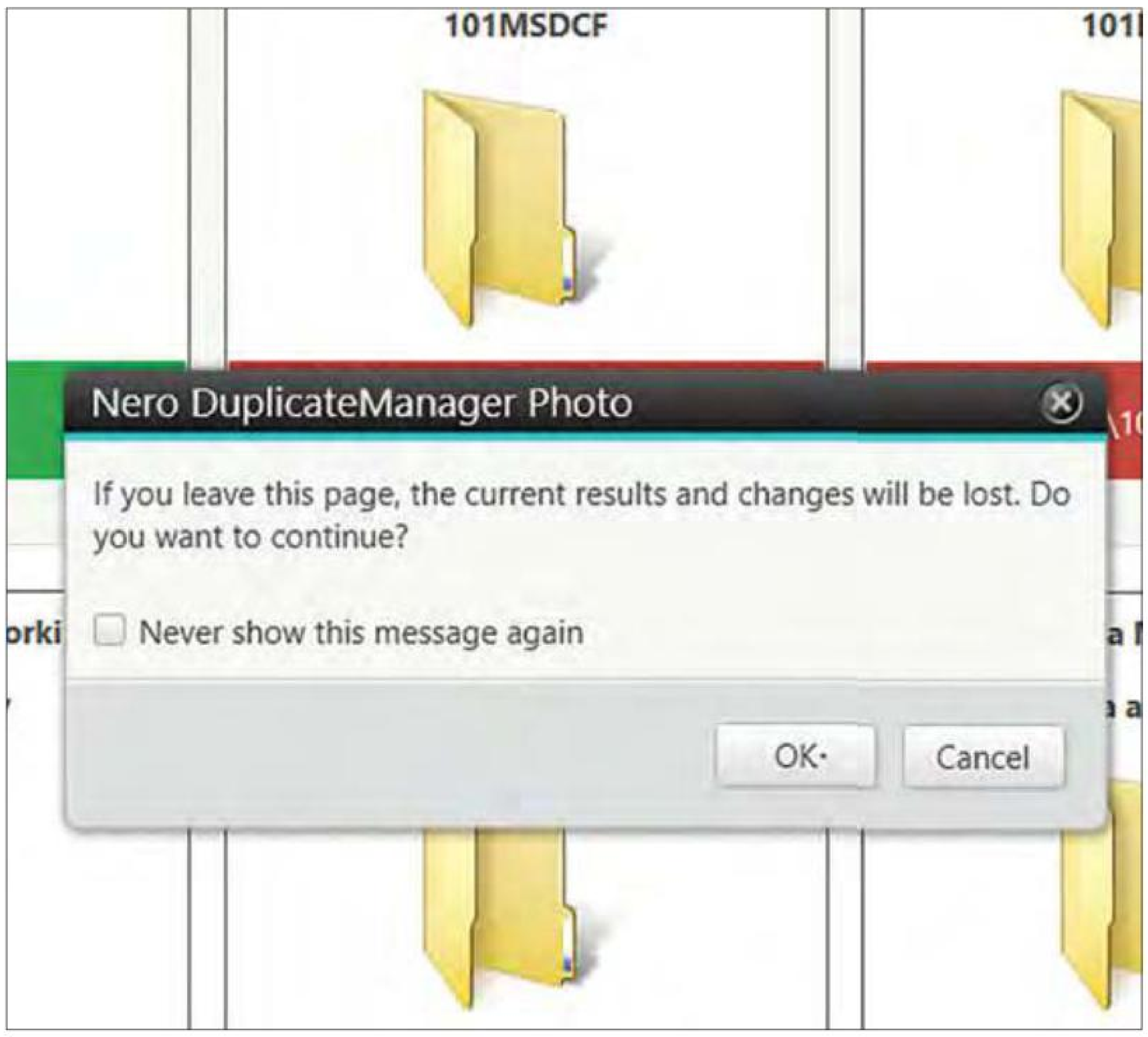
German software company Nero made its name with Burning ROM, a program first released in 1997 that lets a Windows PC burn music CDs. Since then, Nero's software has progressively evolved through numerous generations, which cater for DVDs and Blu-Ray Discs. With an eye to the fact that physical discs are now a declining force in many countries, Nero has expanded into other areas, such as audio and video editing, copying and coding software, PC tune-up, data backup and duplicate file detection and deletion. The original basic software is now free, but the full package, currently called Nero Platinum, costs between £50 (for a year's subscription) and £80 (outright purchase).

The latest version does a much better job of gathering all the disparate applications together into a single interface; previous versions have looked too much like a rag-bag of apps bought in from smaller developers.

Copies of copies

Nero DuplicateManager tackles a real and growing need, as anyone who uses a Windows PC will attest. Unwanted duplicate and closely similar copies of files grow like fungus.

Just the act of trying to copy photo files by pointing and clicking with a mouse can generate unwanted copy files; the act of collating and deleting the copies can then inadvertently create unwanted copies of copies. It's a real nuisance.



Nero DuplicateManager Photo

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Nero DuplicateManager – a good idea, but unnecessarily hard work

My PC is drowning in duplicate copies of audio, video and photo files, some of them deliberately created as safety copies and some there for no apparent reason. On principle, based on bitter experience, I will not install any software with limited life, so jumped at the chance of trying Nero Platinum Unlimited and its DuplicateManager.

After spending several hours analysing a 4TB hard drive store of multimedia files, Nero DuplicateManager finds duplicate photo folders and files, and shows large thumbnails. (Unfortunately Nero does not find duplicate music and movie files). It then uses AI to suggest with red/green marking which exact duplicates can safely be deleted. One Click on Next and they are gone, saving large amounts of disc space.

What's best?

But Nero's AI and I did not agree on what were the best duplicates to delete and the best to keep. Indeed, how could Nero possibly understand my personal preferences? So I restored everything Nero had deleted and started again,

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over-riding Nero's intelligence by selecting a 'keep all' option to mark everything green and then starting on the laborious task of looking at each delete-or-keep choice.

And this is where Nero Duplicate-Manager seriously disappoints. There is no option to save the results of Nero's time-consuming search. All the choose and delete work has to be completed before quitting the program or shutting down the computer. If the PC has to be re-booted – for example, because of an update or a Windows freeze-up or crash – any pending search and analysis data is lost and has to be done again from scratch.

The free option

This is in direct contrast to a very good free program, Duplicate Cleaner Free from Digital Volcano, which saves its search and analysis results through program shut-downs and PC re-boots. Also, Duplicate Cleaner Free handles all multimedia files: audio, video and photos. It's much faster too – scanning the same 4TB HHD took only 20 minutes; probably because Duplicate Cleaner Free does not show thumbnail images.

I asked Nero if I was foolishly missing any option to save unused search results for later, as with Duplicate Cleaner Free. I have not heard back, so I assume not.

As I write this I need to re-boot the PC to get a recalcitrant printer printing again, and to get Outlook to find email again; but I still have to work through 5903 exact duplicate images and 12684 similar images which Nero Duplicate has laboriously listed for action. And that list will need rebuilding again after the re-boot. Have Nero's software engineers never faced a similar Windows re-boot dilemma?

Barry Fox, FBKS (Fellow, International Moving Image Society)

In Search of Simulacra:
Modeling a Self-Learning Android

Photo: interloveupted.blogspo.com
Simulacra: an automated robot mentioned in Homer's Illiad – 700 to 800 BC

The reader is taken through basic understanding of human nature, thinking, learning, problem solving. Then Conceptual information about basic control systems through to Artificial Neural Networks and software architectures is presented. All in plain language. The book goes on to explain the details of how a self-learning Android could work by putting together those previously described control systems.

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Mike & Richard Tooley

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ELECTRONICS TEACH-IN 7
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ELECTRONICS TEACH-IN 8 – CD-ROM
INTRODUCING THE ARDUINO
Mike & Richard Tooley

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Teach-In 8 is an exciting series designed for electronics enthusiasts who want to get to grips with the inexpensive, popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. It will provide a one-stop source of ideas and practical information.

The Arduino offers a truly effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet.

Teach-In 8 is based around a series of practical projects with plenty of information for customisation.

This book also includes *PIC n' Mix*: 'PICs and the PICkit 3 – A Beginners guide' by Mike O'Keefe and *Circuit Surgery* by Ian Bell – 'State Machines part 1 and 2'.

The CD-ROM includes the files for:

- *Teach-In 8*
- Microchip MPLAB IDE XC8 8-bit compiler
- PICkit 3 User Guide
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Not one, but two!

Techno Talk

Mark Nelson

Types of battery, that is. Confused? You won't be, if you've enough charge to reach the end of this article.

Go to your favourite online electronics emporium's website, drill down to batteries and you'll find a vast array of varieties, capacities and sizes. With types suitable for every imaginable application, why on earth would any company contemplate adding to this variety? The answer is obvious – because they can. And who knows, the innovations might well fulfil a vital need.

Not a gimmick?

The two new batteries presented here are certainly attention-grabbers – no gimmicks, according to their entirely serious proponents. For starters, why should batteries be opaque? Might it not be better to make them invisible or at least as inconspicuous as possible? That was the challenge facing researchers at Stanford University, who succeeded in 2011 in creating a small, see-through and flexible lithium-ion battery. It was not totally transparent, however, and appears not to have progressed beyond the proof-of-concept stage.

Fast forward to autumn 2019, the R&D Labs of Japanese telecomms giant NTT (Nippon Telephone and Telegraph) revealed a new type of transparent battery that was clearly more practical. On display in Tokyo were a number of transparent batteries, one of which was a thin plastic 'window pane', the same size as an A4 notepad and as see-through as window glass.

OK, so what does it do and why might you need it? To quote NTT, 'Today, we are surrounded by all kinds of devices. In the future, the presence of these devices could become an eyesore if the number continues to grow. Our goal is to develop devices that adapt to the surroundings.' By selecting a material that easily suppresses light absorption for the electrode and fabricating an electrode that easily suppresses the absorption and reflection of light, they have made a transparent battery with 23% light transmittance, comparable to that of ordinary sunglasses. Another version lets through 69% of light, equivalent to a less-than-ideal piece of window glass.

Scope for development

Future research at NTT will examine the balance between battery performance and transparency according to application. At this stage the performance of these plastic batteries is somewhat underwhelming: a voltage of 1.7V and a discharge capacity of 0.03mAh. You would need a battery of approximately 4.5m^2 to achieve capacity equivalent to a CR1025 coin cell. However, the transparent battery can also operate as a rechargeable secondary battery that can light an LED even after being discharged and charged 100 times. What's more, it is also flexible, and its electrodes can be formed on conductive films with gelatine electrolytes. A wide range of potential applications is envisaged, including wearable devices, information displays and integration into construction materials such as the windows of buildings.

Edible capacitors?

Capacitors are increasingly employed as effective batteries. That's certainly the intention for the type described next – but 'edible'? Well, not really, although this new kind of energy invention was inspired by croissants.

Dr Emiliano Bilotti and his team of researchers at Queen Mary University of London (Queen Mary College, as was) developed it. In itself it's nothing more than a polymer film capacitor, which uses an insulating plastic film as the dielectric. They first came to most people's attention as the colourful and stripy 'tropical fish' capacitors introduced by Mullard (see **http://bit.ly/pe-feb20-fish** for a memory jerker). You can buy their modern equivalents for pence from your favourite component supplier and many of you have certainly used them in your projects. However, despite their numerous advantages over other types of capacitor (**http://bit.ly/pe-feb20-cap**), they tend to be physically larger than alternative varieties and this is an obvious drawback that Dr Bilotti's team have now countered.

Bakers make croissants by layering and pressing dough, a technique the Queen Mary team have mimicked by pressing and folding their capacitor's polymer film. They were able to store 30-times more energy than the best-performing commercially available dielectric capacitor, achieving the highest energy density ever reported in a polymer film capacitor.

Storing intermittent energy

The significance of this is most timely. It is widely agreed that we need to substitute power generated using fossil fuels (to combat climate change) with renewable energy (for example, solar and wind). Consequently, we need to develop affordable, efficient, low-cost and environmentally friendly systems for storing electric energy. As Dr Bilotti explains, 'storing energy can be surprisingly tricky and expensive, and this is problematic with renewable energy sources which are not constant and rely on nature. With this technique we can store large amounts of renewable energy to be used when the sun is not shining and it is not windy.'

These 'pastry power' capacitors, with their ultra-high power density, should be ideal for the function just described. Other electrochemical energy storage technologies exhibit disappointingly low power density or use exotic materials.

Yet more applications

The ability of croissant capacitors to accumulate energy over a period of time and then release it almost instantly means they could find numerous industrial applications; for example, motor drives, mobile power systems, space vehicle power systems and electrochemical guns.

Professor Mike Reece, one of Dr Bilotti's colleagues, clarifies: 'This finding promises to have a significant impact on the field of pulse-power applications and could produce a step change in the field of dielectric capacitors, so far limited by their low energy-storage density. Even better, although achieving high energy density in polymer film capacitors normally involves complex and expensive production processes, the new pressing and folding technique is unique for its simplicity, record high energy density and potential to be adopted by industry.'

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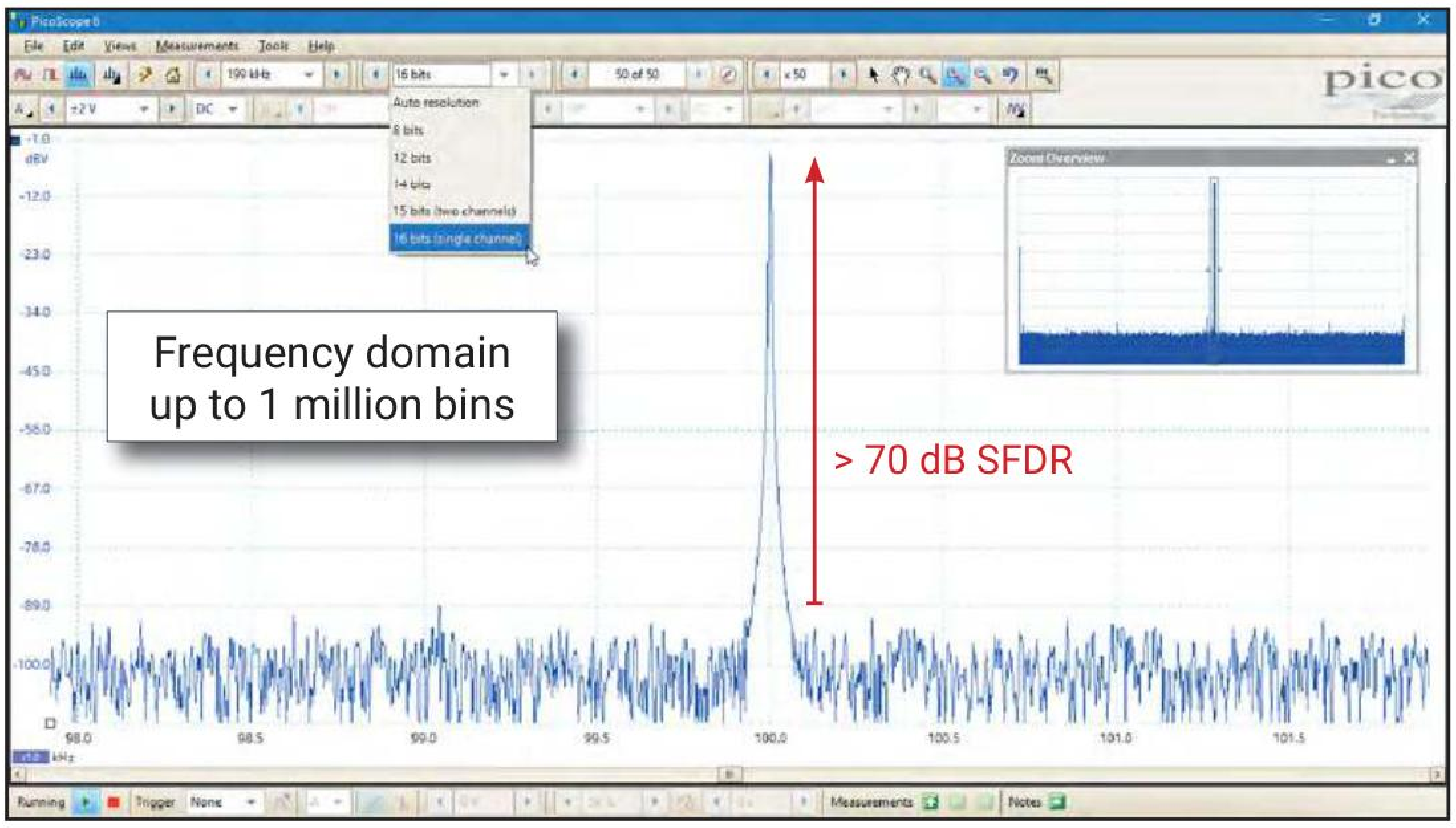
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Net Work

Alan Winstanley

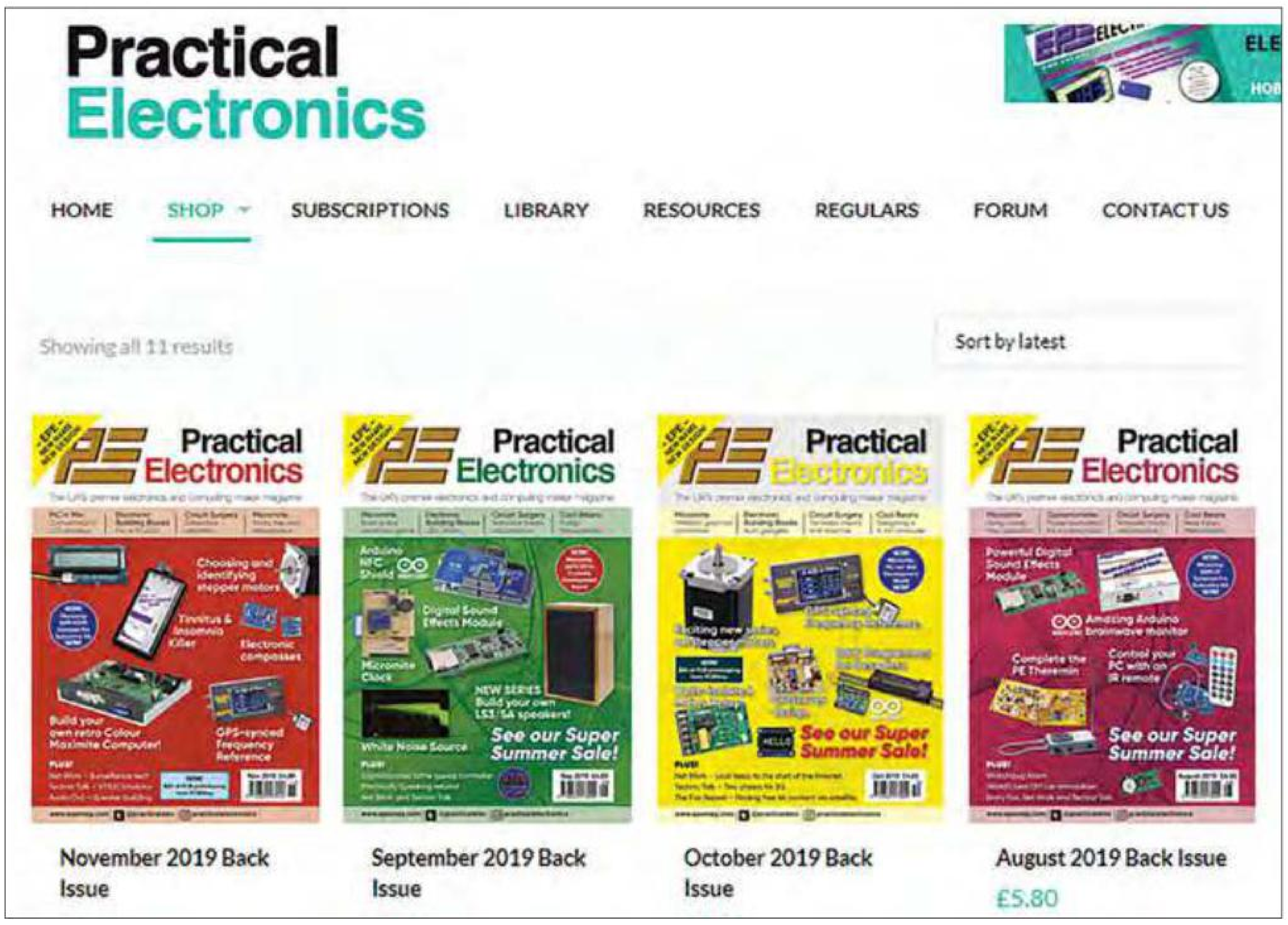
This month, the big news is the launch of our new online shop. It's a significant upgrade from our previous virtual store and lays the foundation for a whole new web presence for *Practical Electronics*.

Regular readers will be aware that about a year ago your favourite hobby electronics magazine came under the fine stewardship of a new publisher; namely, our editor Matt Pulzer. Matt works tirelessly to bring readers and subscribers a monthly journal crammed with plenty of electronic projects, theory and tutorials – enough to keep the most industrious hobbyist very busy during the forthcoming winter season!

Our website at **https://www.epemag.com** is the place to go to learn more about the current edition, or to download any source code files relating to that month's issue. The website has served us well since its launch back in 2012 but, as it was built purely on 'static' HTML, it presents challenges in terms of navigation and scalability, and there is the need to improve usability on portable devices like tablets and Chromebooks too. Our online presence is therefore receiving a well-overdue makeover using modern web design, navigation and hosting techniques. This task has been under way for quite some time under the tutelage of our new web systems manager Kris Thain, who is the latest addition to the *PE* staff line-up.

New shop

A key stage of our website redevelopment was successfully reached last November, when we launched a completely redesigned shopping cart to introduce convenient new design features along with a fresh new look. You can still buy back issues, books, CDROMs and more, and we ship worldwide as usual. You can also phone through an order or snail mail it to us with a GBP cheque payable to 'Practical Electronics'. Existing customers' details have been migrated to the new shopping cart, so regular users of the *PE Online Shop* should be able to log in as before. Details of our subscription options (printed copy, PDF download or Pocketmags edition) are provided as well. Last, an important reminder: subscribers to the print edition now click through to our new subscription service provider – *Select* – who can set you up with a direct debit, so you don't need to remember to renew every year.



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November 2019 Back Issue

September 2019 Back Issue

October 2019 Back Issue

August 2019 Back Issue
£5.80

Work on redesigning and modernising the *PE* website and Online Shop is well under way. Come and take a look!

At the same time, we're also modernising our downloads system with a slick new service: monthly source code .zip files will be hosted in the Online Shop as a free download, though you will need to create an online account if you don't already have one. Download histories are then stored and accessible in your personal account, enabling you to keep track of them in the future. A limit of three downloads of any one .zip file is allowed, but we would like to re-assure readers that we'll always try to help out if another copy is needed later down the line. Just drop me an email.

It's an exciting time for *Practical Electronics* as we endeavour to modernise our web presence. Everything is being handled by the *PE* team in-house and we're working hard to provide customer services, consolidate a new online store, bring in legacy magazine resources and more material under a fresh new banner. For now, we'd like to thank readers for being patient while work on our web presence is ongoing. We're almost there – the occasional missing image will be filled in, pages will be duly populated and links to legacy material will be updated.

Shop till you drop

After Black Friday and last November's 'Cyber Monday' online shopping binge, Amazon announced that its Cyber Monday turnover had been the largest single shopping day in its corporate history. Amazon's fashion arm did well too, boasting record-breaking sales: 'Best-sellers included Carhartt Men's Acrylic Watch Hat and Champion Men's Powerblend Fleece Pullover Hoodie,' Amazon declared triumphantly (which explains the Ed's new attire). Independent traders selling in Amazon's stores got a slice of the cake too; they sold more merchandise on Cyber Monday than in any other 24-hour period in Amazon's history, the firm said.

One thing I must admit to, dear readers, is that I finally buckled under the Black Friday pressure and found myself enrolled in Amazon's Prime package at £7.99 a month. The 'perks' of Prime membership have been drilled into us and it must be said that Amazon's website, a Fire TV Stick and the Amazon app on a smart TV all picked up my Prime membership faultlessly.

It has been said that our behaviour changes when we subscribe to services this way: since we are now paying for a subscription, we may as well use it, though Amazon will refund fees (on application) if Prime is not used in any particular month. Although many Amazon Prime movies are still rented the normal way, several free videos, a music track or two and a few next-day parcels later (18-hour delivery, in one case), I fear that I'm hooked.

The Western market for smart speakers such as Amazon's Echo range continues to explode, but Google's Nest range fared less well, according to analysts Canalys in their survey of Q3 2019 unit sales. Amazon grabbed 36% of the global market share with sales of over ten million units, three times more than Google sold in the same period. Other brands and devices that mainly serve the Asian markets included Alibaba's Tmall Genie, plus Xiaomi and Baidu brand speakers, which all grew in sales volumes, while Google's sales plunged by 40%. The global market for smart displays (those with an LCD screen) expanded five-fold, reports Canalys, showing where future consumer interest is heading.

Not the case

A tech retailer disappointed the author when he bought a Samsung A10 2019 tablet with a bundled 'starter kit' case during the Black Friday period. The case proved to be an obsolete '2018' model that does not fit Samsung's 2019 tablet, as if consumers should know the difference: the rear camera cut-out is in the wrong place and the case is too large. Another retailer had pulled the same trick, judging by reviews. Surfing a few days later, pop-up ads promised an even cheaper price (darn!), but no stock was readily available either for delivery or for in-store collection (phew!). It's time retailers stopped such misleading advertising; under UK consumer protection law, the practices of 'bait advertising' (where little or no stock is available) and 'bait and switch' (dangling an offer for unavailable merchandise, hoping to switch interested buyers onto something pricier), are illegal abusive practices. Meanwhile, Amazon listed a suitable tablet case by the same vendor in two different places, at significantly different prices. It pays to shop around.

Scan
ADF
Scan to Cloud
Output Tray
Scan to Computer (JPEG)
Back
Scan to Computer (PDF)

Google Cloud Print will close in December 2020, so home users will need to use the hardware's native services instead.

Facebook's Portal screens offer family friendly video calling on smart devices or TVs. 'User experience may vary,' says Facebook.

And finally

Facebook is shipping its second-generation 'Portal' smart LCD screens, not seen in the UK before now. It offers family friendly video chat with webcam-style augmented reality (AR) masks for fun and games. The standalone Portal screens range from 8-inch to 15.6-inch and TV-connected devices enable video calls to be enjoyed on a wide screen. They can access Alexa, WhatsApp, Messenger, Amazon Prime or act as a digital photo frame. Portal will be ideal for many families, but some early adopters have complained about poor performance, claiming they need superfast broadband. 'User experience may vary,' says the caption in Facebook's jitter-free promo video. Learn more at: **https://portal.facebook.com**

Google is giving up on Google Cloud Print, its cloud-based printer driver. The service, which has been in beta since 2010 (!), will close at the end of 2020. Users who send print jobs or photos over the web to their network printer should switch to their printer's own cloud service [eg Epson Connect or HP ePrint] instead, says Google. More details at **http://bit.ly/pe-feb20-googend** and a shortlist of some affected printers is at **http://bit.ly/pe-feb20-print**

One of the largest leaks of personal data in history occurred in November 2019 when details of more than 1.2 billion individual users were left wide open on a Google Cloud server. Data included a wide range of personal information and LinkedIn profiles. At the time of writing, the source of the massive breach had largely been narrowed down to servers connected with the data aggregation company PDL (People Data Labs). You can see if you're affected by entering your email address in: **https://haveibeenpwned.com/**

Amid rows between the US, France, the UK and the rest of the world about digital service taxation, the OECD has outlined proposals for a 'unified approach' to taxing the profits of consumer-facing multinational corporations (MNCs) such as Facebook and Google that shift digitally generated profits to more tax-efficient havens. The UK initially abandoned its efforts to tax MNCs' profits on 'soft' digital services such as marketing or advertising fees.

Huawei battles onwards in the teeth of a US trade embargo. The firm's new Mate 30 smartphone is said to contain no US-made components at all, and uses Huawei's own app store; the lack of any OEM-installed Google services may not be an issue in Asian markets in any case. In Russia, the pre-installation of Russian-origin software on smartphones, TVs and tablets became mandatory on 1 January.

In the UK, telecoms seller O2 has switched on its first 5G network, promising users unlimited high-speed data in 50 towns and cities by next summer. O2 is focussing on commercial areas and transport hubs first. A coverage checker is at: **http://bit.ly/pe-feb20-o2**

Attention Windows users!

Some 27.5% of Windows desktop users are still using Windows 7, and PC makers hope for a mass exodus onto Windows 10 once W7 support finally ends on 14 January. About 5% still use Windows 8 and 1.3% remain committed to Windows XP, says Global StatsCounter. The uptake of macOS 10.15 has climbed to 27% and is soon set to overtake macOS Mojave.

Finally, I never did find out what the mysterious Ethernet port on the rear of a new LG Full HD TV (see *Net Work*, December 2019) was for. It is not a 'smart' TV and I suspect it only fetches firmware downloads over the web. Following on from my Freeview item in the same issue, I hope to explore some other ways of receiving Freeview over a network in the next few columns. See you next month for more *Net Work!*

The author can be reached at:
alan@epemag.net

Win a Microchip MCP3564 ADC Evaluation Board for PIC32 MCUs

Practical Electronics is offering its readers the chance to win a Microchip MCP3564 ADC Evaluation Board for PIC32 MCUs (ADM00583).

The MCP3564 ADC Evaluation Board for PIC32 MCUs enables developers to evaluate the performance of the MCP3564. It provides a development platform for 32-bit-PIC device-based applications, using existing 100-pin PIC microcontroller Plug-in Module (PIM) systems that are compatible with the Explorer 16 and other high-pin-count PIC32 device-based demo boards. The system comes with a programmed PIC32MX795F512L PIM module that communicates with the Energy Management Utility software for data exchange and ADC setup.

The 24-bit MCP356x and 16-bit MCP346x delta-sigma ADC families offer faster programmable data rates over similar devices on the market, while providing high accuracy and lower-noise performance. Available in a tiny 3mm × 3mm UQFN-20 package, these highly integrated ADCs meet increasing demand for small packaging in space-constrained applications such as portable instrumentation devices.

Most high-resolution delta-sigma ADCs on the market have slower programmable data rates of a few kSPS. The MCP356x and MCP346x families offer a much faster data rate, making the devices ideal for a variety of precision applications that require different data speeds, including industrial process control, factory automation and sensor transducers and transmitters. The ADCs also offer integrated features to eliminate the need for external components and reduce the overall cost of a system, including an internal oscillator, temperature sensor and burnout current source.

The new families provide 24-bit or 16-bit resolution, two/four/eight single-ended or one/two/four differential channel options, allowing developers to choose the most suitable ADC for their designs. The devices join Microchip's extensive portfolio of versatile ADCs that meet the needs of a variety of speed, accuracy and power-consumption requirements.

The MCP3564 ADC evaluation kit (ADM00583) is available to demonstrate the performance of the MCP356x family and includes the following components:

- MCP3564 ADC Evaluation Board for PIC32 MCUs
- PIC32MX795F512L PIM
- USB cable

Worth $130.00 (approx £103) each

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The closing date for this offer is 29 February 2020.

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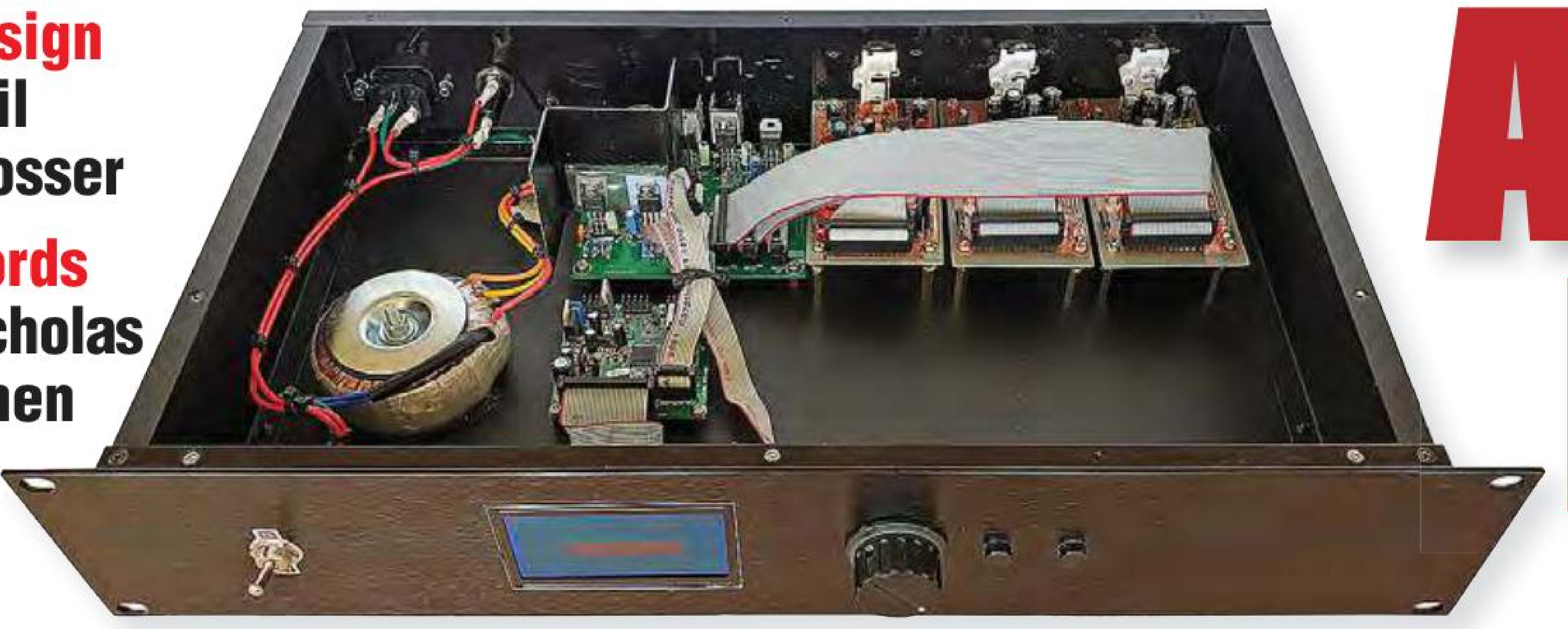


Audio DSP

Part 2

This is an exciting project, but what exactly is it? A digital signal processor? – a two-way active crossover? – or perhaps an 8-channel parametric equaliser? In fact, it is all of these… and more.

We introduced our new, very versatile Hi-Fi stereo digital signal processor (DSP) last month. As we said then, it is a monster project, built with seven modules. Based around a powerful 32-bit PIC processor and high-quality analogue-to-digital (ADC) and digital-to-analogue (DAC) converters, it can be used as a two-way active crossover and/or a multi-band parametric equaliser – and much more! In this second instalment, we finish describing the circuit and present the parts list and board assembly instructions.

We rather left you hanging at the end of the article last month, because we didn't have room to describe all the circuitry in this advanced device. We'll rectify that shortly, covering the CPU board and some extra bits and pieces before we get into the assembly of the various modules.

If you haven't read the first article in the January issue, we suggest that you do so now, since this is a complex and capable design. But let's just briefly revisit its capabilities before continuing the circuit description.

This device accepts a stereo line-level audio signal (from a disc player, MP3 player, smartphone… or even a cassette deck or turntable with preamp) and converts it to high-quality digital data.

It then sends it to a 32-bit processor which processes the signal to split it into high and low frequencies, apply any necessary delays, gain and equalisation before feeding the results to two Hi-Fi stereo DAC boards.

These convert the digital signals back into two pairs of stereo signals, which can then be fed onto individual power amplifiers for the woofers and tweeters.

It's controlled using a graphical LCD, rotary encoder and two pushbuttons, and the configuration is stored in EEPROM, so you don't have to set it up each time.

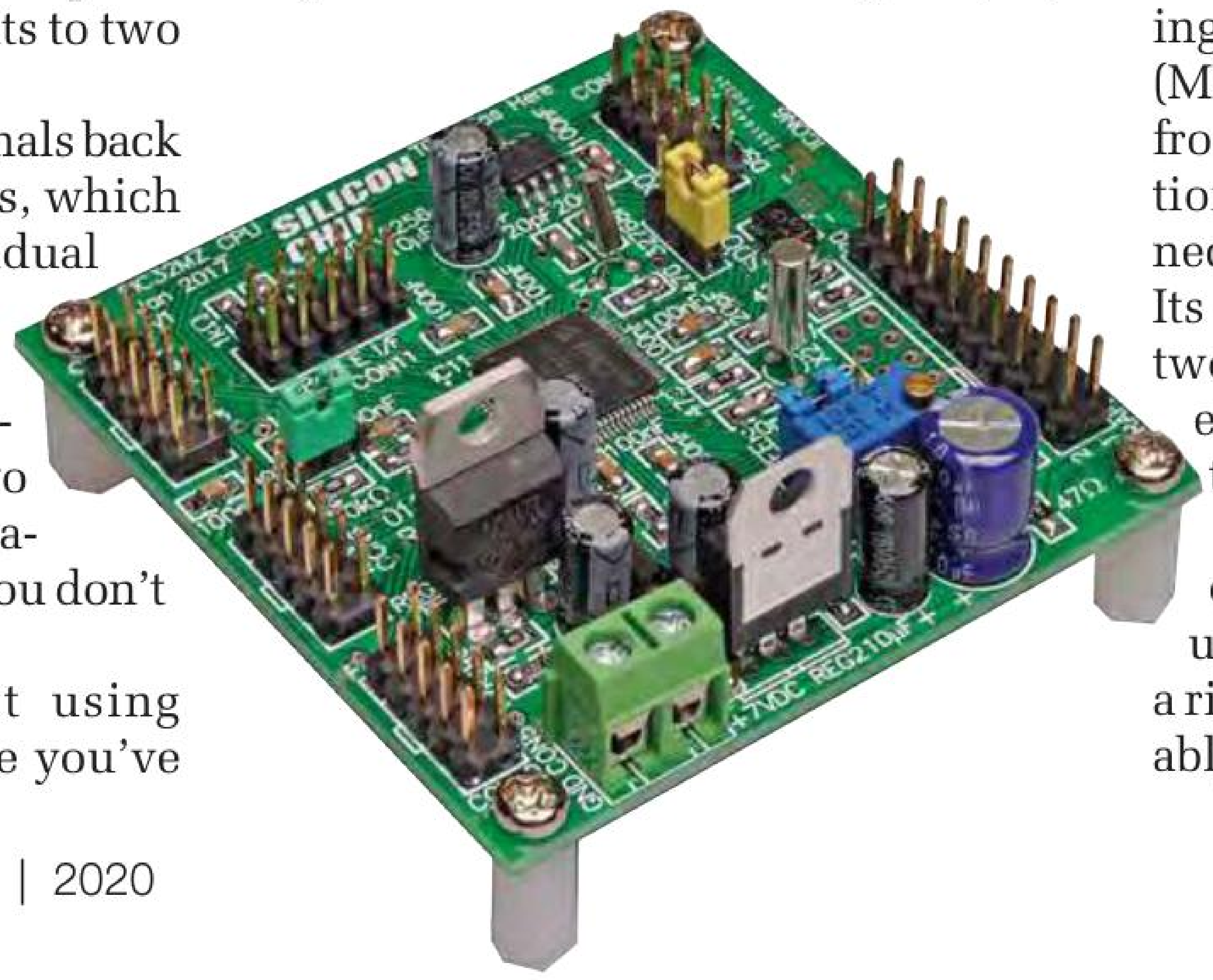
For flexibility, It's built using seven distinct modules. Once you've assembled these, you can connect them together and test the system as a whole, then start work on putting it all together in a proper case and integrating it with a Hi-Fi system. But before we get to that stage, we need to finish describing how it works. So let's get back to it.

Microcontroller board

The circuit of the microcontroller board is shown in Fig.7. This is designed so that it can be used in other projects (just as you can the ADC and DAC boards).

Microcontroller IC11 is a PIC32MZ2048 32-bit processor with 2MB Flash, 512KB RAM and which can run at up to 252MHz. It has a USB interface which is brought out to a micro type-B socket (CON6) although we haven't used it in this project – it's there 'just in case' for other projects.

The PIC is also fitted with an 8MHz crystal for its main clock signal (X2).



Provision is made on the PCB (and shown in the circuit) for a 32.768kHz crystal for possible future expansion, but they are not used in this project and can be left out.

There is also provision for an onboard serial Flash (IC12) which is connected via one of the hardware SPI ports.

Two of the other audio-capable SPI ports are wired up to CON7, which connects to CON17 on the power supply/signal routing board (described last month), and therefore ultimately to the ADC and DAC boards.

LK1 allows two different pins to be used for SDO4 (serial data output #4); this function can be internally reconfigured in IC11, and since some functions are shared, there may be times where you want to use the alternative pin.

CON11 on this board connects to CON18 on the power supply/routing board and feeds the master clock (MCLK) through to the ADC and DACs, from output pin RE5 of IC11. As mentioned earlier, the other I/O pins connect to the front panel control board. Its circuit is shown in Fig.8. It carries two pushbutton switches and a rotary encoder, which are used to scroll through menus and make selections.

The user interface is displayed on a graphical LCD, which is wired up to CON8 on the micro board, via a ribbon cable. This provides a reasonably standard 8-bit parallel LCD drive

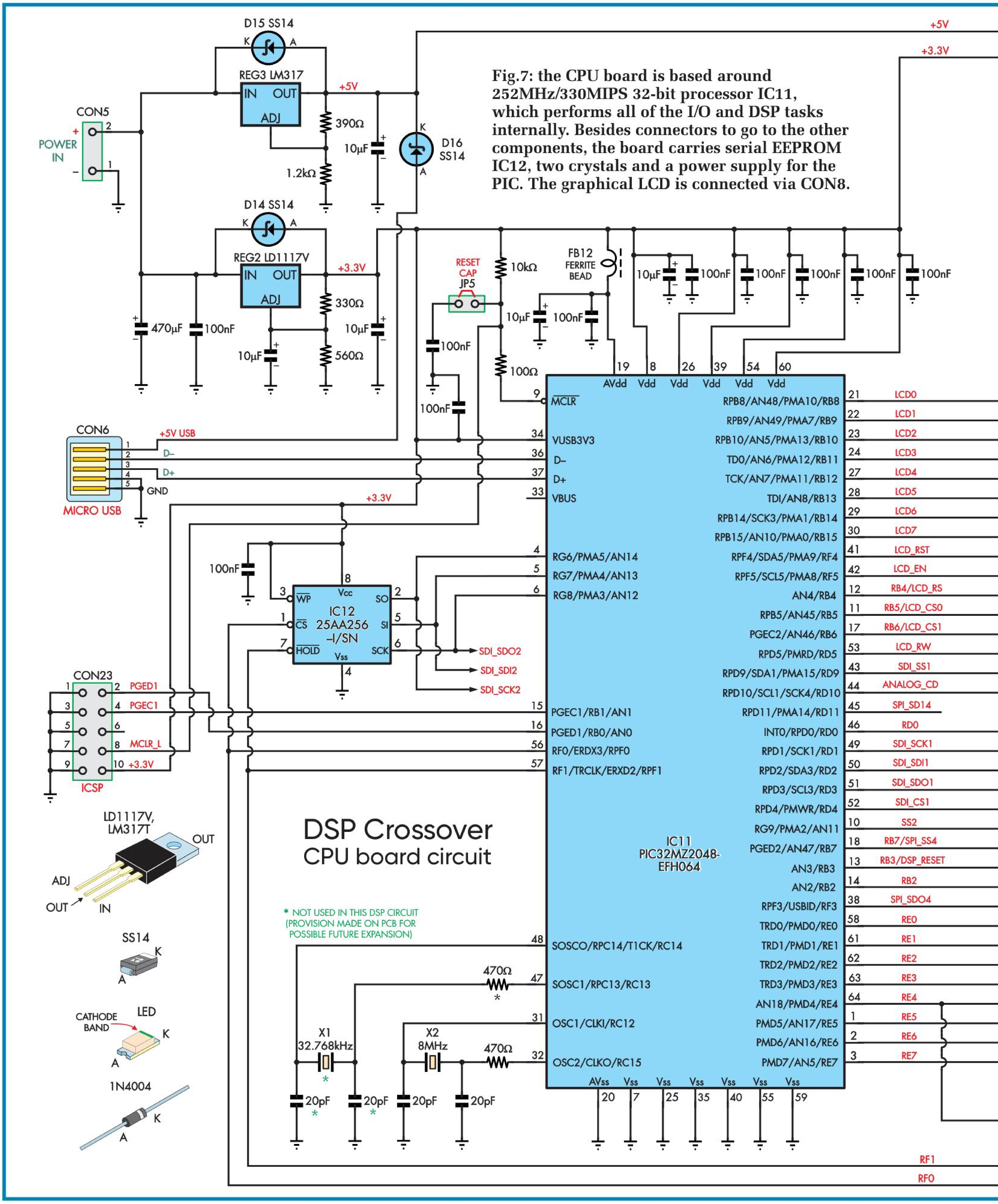


Fig.7: the CPU board is based around 252MHz/330MIPS 32-bit processor IC11, which performs all of the I/O and DSP tasks internally. Besides connectors to go to the other components, the board carries serial EEPROM IC12, two crystals and a power supply for the PIC. The graphical LCD is connected via CON8.

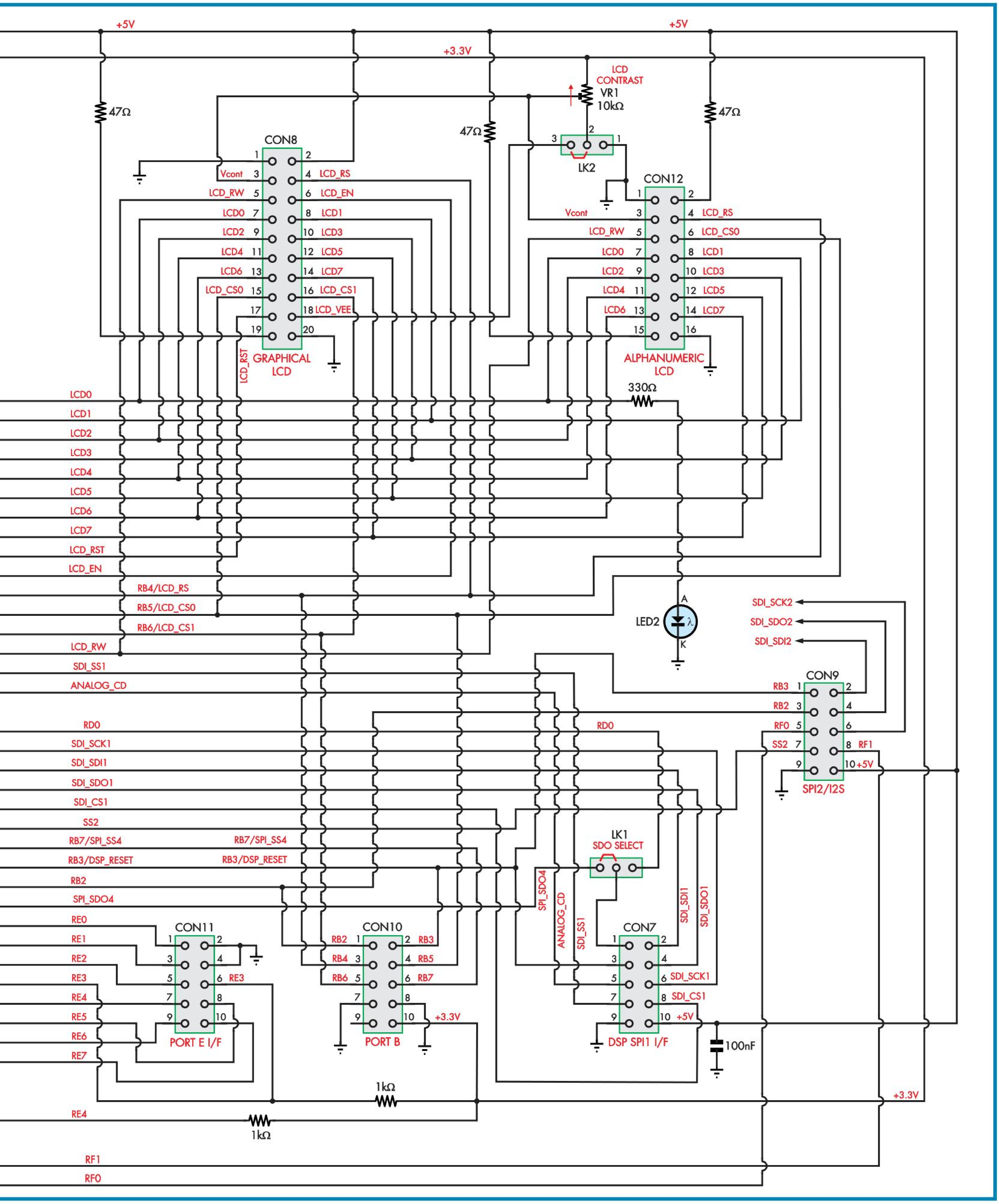
DSP Crossover
CPU board circuit
D15 SS14
REG3 LM317
IN
OUT
ADJ
+5V
390Ω
1.2kΩ
10μF
D16
SS14
K
A
CON5
POWER IN
+
–
D14 SS14
REG2 LD1117V
+3.3V
330Ω
560Ω
470μF
100nF
RESET CAP
JP5
10kΩ
100Ω
FB12
FERRITE BEAD
CON6
+5V USB
D–
D+
GND
MICRO USB
IC12
25AA256
–I/SN
Vcc
WP
CS
HOLD
Vss
SO
SI
SCK
SDI_SDO2
SDI_SDI2
SDI_SCK2
CON23
PGED1
PGEC1
MCLR_L
ICSP
IC11
PIC32MZ2048-
EFH064
AVdd
Vdd
MCLR
VUSB3V3
VBUS
RG6/PMA5/AN14
RG7/PMA4/AN13
RG8/PMA3/AN12
PGEC1/RB1/AN1
PGED1/RB0/AN0
RF0/ERDX3/RPF0
RF1/TRCLK/ERXD2/RPF1
SOSCO/RPC14/T1CK/RC14
SOSC1/RPC13/RC13
OSC1/CLKI/RC12
OSC2/CLKO/RC15
AVss
Vss
RPB8/AN48/PMA10/RB8
RPB9/AN49/PMA7/RB9
RPB10/AN5/PMA13/RB10
TD0/AN6/PMA12/RB11
TCK/AN7/PMA11/RB12
TDI/AN8/RB13
RPB14/SCK3/PMA1/RB14
RPB15/AN10/PMA0/RB15
RPF4/SDA5/PMA9/RF4
RPF5/SCL5/PMA8/RF5
AN4/RB4
RPB5/AN45/RB5
PGEC2/AN46/RB6
RPD5/PMRD/RD5
RPD9/SDA1/PMA15/RD9
RPD10/SCL1/SCK4/RD10
RPD11/PMA14/RD11
INT0/RPD0/RD0
RPD1/SCK1/RD1
RPD2/SDA3/RD2
RPD3/SCL3/RD3
RPD4/PMWR/RD4
RG9/PMA2/AN11
PGED2/AN47/RB7
AN3/RB3
AN2/RB2
RPF3/USBID/RF3
TRD0/PMD0/RE0
TRD1/PMD1/RE1
TRD2/PMD2/RE2
TRD3/PMD3/RE3
AN18/PMD4/RE4
PMD5/AN17/RE5
PMD6/AN16/RE6
PMD7/AN5/RE7
LCD0
LCD1
LCD2
LCD3
LCD4
LCD5
LCD6
LCD7
LCD_RST
LCD_EN
RB4/LCD_RS
RB5/LCD_CS0
RB6/LCD_CS1
LCD_RW
SDI_SS1
ANALOG_CD
SPI_SD14
RD0
SDI_SCK1
SDI_SDI1
SDI_SDO1
SDI_CS1
SS2
RB7/SPI_SS4
RB3/DSP_RESET
RB2
SPI_SDO4
RE0
RE1
RE2
RE3
RE4
RE5
RE6
RE7
RF1
RF0
+5V
+3.3V
X1
32.768kHz
X2
8MHz
470Ω
20pF
* NOT USED IN THIS DSP CIRCUIT (PROVISION MADE ON PCB FOR POSSIBLE FUTURE EXPANSION)
LD1117V,
LM317T
ADJ
OUT
IN
SS14
LED
CATHODE BAND
1N4004

interface. The eight LCD data lines (DB0-DB7) are driven from a contiguous set of digital outputs of IC11 (RB8-RB15). This allows a byte of data to be transferred to the display with just a few lines of code and minimal delay.

The other LCD control lines are driven by digital outputs RB4, RB5, RB6, RD5, RF4 and RF5 and the screen is powered from the 5V rail. The backlight brightness is set with a 47Ω resistor. LCD contrast is adjusted using trimpot VR1, which connects to CON8 via LK2.

LK2 is provided so that VR1 can also be used to set the contrast on an alphanumeric LCD, which can be fitted in place of the graphical one and controlled by the same pins (via CON12). But again, we are not using that in this project. As we said above, this board is intended to be generic, so it has a few options we are not using.

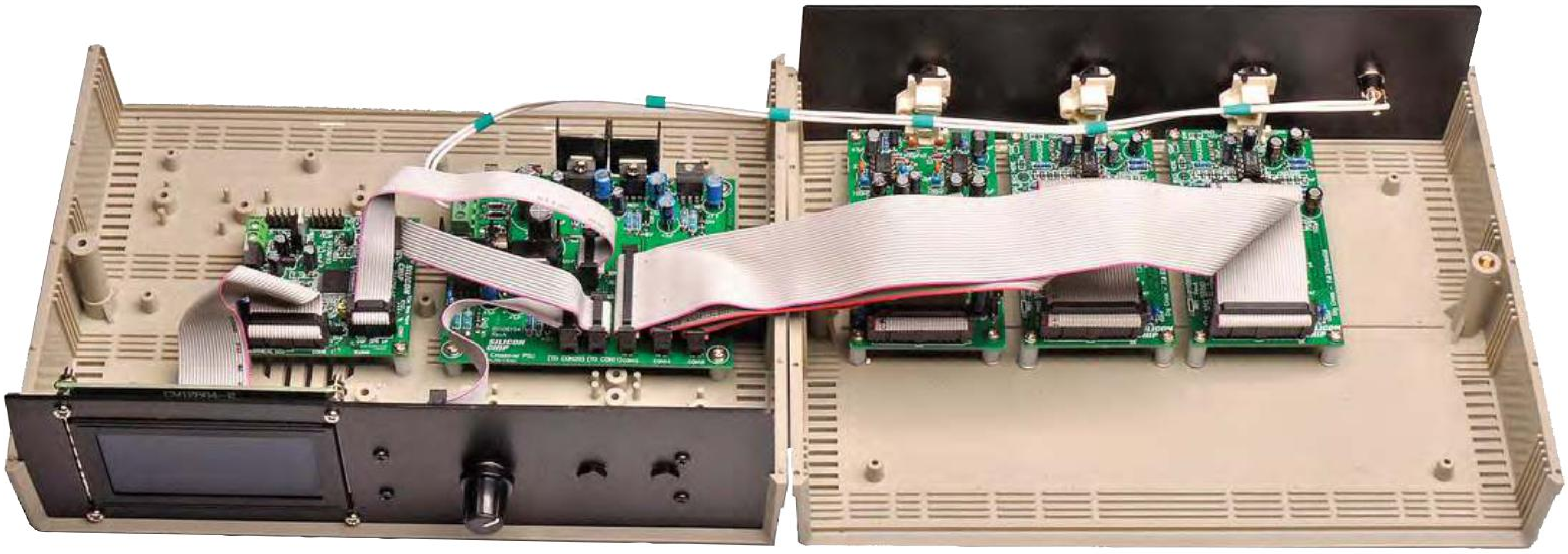
CON23 is a somewhat unusual in-circuit serial programming (ICSP)


+5V
+3.3V
+5V
47Ω
47Ω
47Ω
LCD
CONTRAST
VR1
10kΩ
LK2
CON8
Vcont
LCD_RW
LCD0
LCD2
LCD4
LCD6
LCD_CS0
LCD_RS
LCD_EN
LCD1
LCD3
LCD5
LCD7
LCD_CS1
LCD_VEE
LCD_RST
GRAPHICAL
LCD
CON12
Vcont
LCD_RW
LCD0
LCD2
LCD4
LCD6
LCD_RS
LCD_CS0
LCD1
LCD3
LCD5
LCD7
ALPHANUMERIC
LCD
330Ω
LCD0
LCD1
LCD2
LCD3
LCD4
LCD5
LCD6
LCD7
LCD_RST
LCD_EN
RB4/LCD_RS
RB5/LCD_CS0
RB6/LCD_CS1
LCD_RW
SDI_SS1
ANALOG_CD
LED2
A
K
SDI_SCK2
SDI_SDO2
SDI_SDI2
CON9
RB3
RB2
RF0
SS2
RF1
+5V
SPI2/I2S
RD0
SDI_SCK1
SDI_SDI1
SDI_SDO1
SDI_CS1
SS2
RB7/SPI_SS4
RB3/DSP_RESET
RB2
SPI_SDO4
RE0
RE1
RE2
RE3
RE4
RE5
RE6
RE7
RD0
RB7/SPI_SS4
RB3/DSP_RESET
LK1
SDO SELECT
SPI_SDO4
ANALOG_CD
SDI_SS1
SDI_SDI1
SDI_SDO1
CON11
RE3
PORT E I/F
CON10
RB2
RB4
RB6
RB3
RB5
RB7
+3.3V
PORT B
CON7
SDI_SCK1
SDI_CS1
+5V
DSP SPI1 I/F
100nF
1kΩ
1kΩ
RE4
+3.3V
RF1
RF0

header. It has a similar pinout to a PICkit 3/4 but is not directly compatible; it's designed to work over a longer cable. Since each signal line has at least one ground wire between it, signal integrity should be better.

Jumper leads could be used to make a quick connection to a PICkit to program the microcontroller the first time. Or you could attach a 10-pin IDC connector to the end of a ribbon cable and then solder the appropriate wires at the other end of the cable to a 5-way SIL header as a more permanent programming adaptor for development use.

There are two regulators on the board; REG3 derives a 5V supply from 7V+ DC applied to CON5, which is used to power the LCD screen and is also fed to CON7 and CON9. REG2 is used to produce a +3.3V rail from the same source (CON5), to power microcontroller IC11 itself.



The completed unit mounted in the two halves of an instrument case. An alternative would be a 2U rack-mounting case.

However, note that in this project, we're not feeding power in via CON5. Instead, the 5V supply comes from the main power supply board over the ribbon cable to CON7. It then powers the LCD screen and flows through schottky diode D15 to the input of REG2, which then powers REG2 and thus the 3.3V rail for the micro.

We're also not using the USB interface or USB connector CON6 in this project, nor are we using the extra microcontroller I/O pins which are broken out to headers CON9 or CON10. CON9 could potentially be used to connect another ADC and/or DAC board in other applications where more channels may be necessary (eg, a three-way crossover).

LED2 is connected from LCD data line LCD0 to ground, with a 330Ω current-limiting resistor, so it will flash when the LCD screen is being updated.

Front panel board

The front panel circuit (Fig.8) was mentioned above. In addition to the two pushbuttons and rotary encoder, there are four 4.7kΩ resistors shown, but only two of these are actually fitted.

These resistors indicate to the CPU board what type of rotary encoder has been fitted and therefore how to interpret the data from it.

R3 and R4 are fitted when using a standard gray code or 'quadrature' rotary encoder, which is a standard encoding method but not used by either of the encoders we tested.

R1 and R4 are fitted when an encoder is used which produces the same quadrature signals but it goes through one complete (four-pulse) cycle for each step that the encoder is rotated (ie, 11 -> 10 -> 00 -> 01 -> 11 clockwise or 11 -> 01 -> 00 -> 10 -> 11 anti-clockwise). This is the code that the Altronics S3350 rotary encoder produces.

R2 and R3 are fitted for an encoder which produces three state changes per click (11 -> 10 -> 00 -> 11 clockwise or 11 -> 01 -> 00 -> 11 anti-clockwise). This is the code that the Jaycar SR1230 rotary encoder produces. If this encoder is used, S1 does not need to be fitted as the encoder has an internal pushbutton, activated by pressing in the knob, which is connected in parallel with S2.

The two 22nF capacitors help to debounce the signals from the rotary encoder, to ensure that it works reliably.

Debouncing is also performed in software, but it helps to have the hardware to reduce glitches at the digital inputs.

The PCB has two different mounting locations for the two possible rotary encoders, because the Jaycar SR1230 is a vertical type, while Altronics S3350 is right-angle mounting.

Therefore, if using the Altronics encoder, you would either need to chassis-mount the pushbuttons and wire them back to the board, or surface-mount the encoder on the board so that it is vertical (more on that later).

Construction

Start by assembling the PCBs, all of which are available in a pack of six from the *PE PCB Service*. We'll do that in the same order that we presented the circuit, starting with the ADC board. This is built on a PCB coded 01106191, measuring 55.5 × 102mm. The overlay diagrams for this board are shown in Fig.9.

It has parts on both sides – SMDs on the bottom and through-hole on the top, so both sides are shown in Fig.9.

It's best to fit all the SMD parts to the underside first, starting with IC1. This is the only fine-pitch part on the board. It comes in a 24-pin TSSOP package. First, identify the pin 1 dot printed on its top surface and orient the part so that dot is towards the nearby DIL header, as shown. Then put a little solder on one of the corner pads and heat that solder while sliding the chip into position.

Use a magnifier to check that all the pins on both sides are correctly lined up with their pads. If not, re-heat the solder on that one pin and gently nudge the IC ever so slightly in the correct direction. Repeat until it is

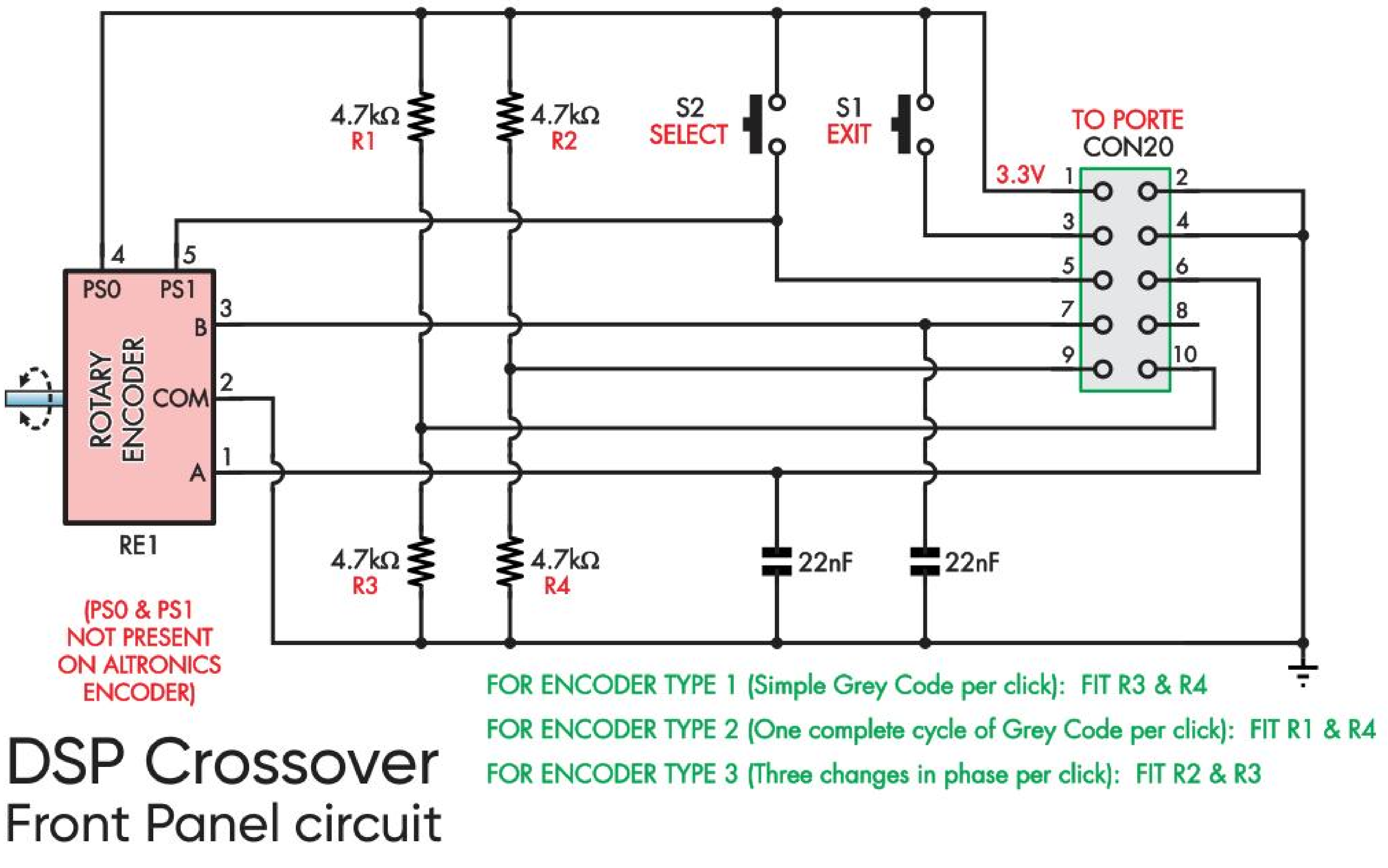
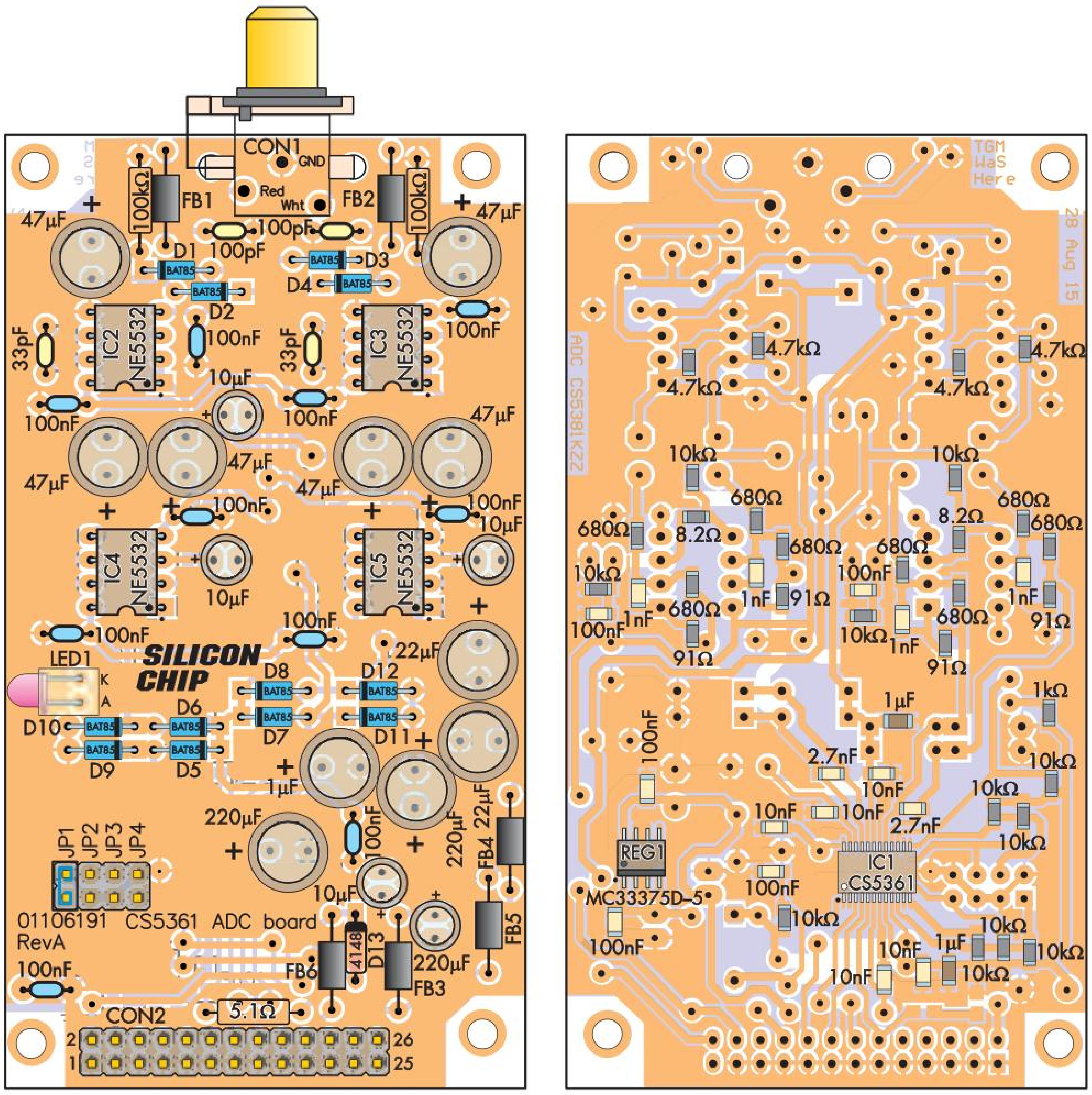

4.7kΩ
R1
4.7kΩ
R2
S2
SELECT
S1
EXIT
TO PORTE
CON20
3.3V
1
2
3
4
5
6
7
8
9
10
4
5
PS0
PS1
3
B
ROTARY ENCODER
COM
2
1
A
RE1
4.7kΩ
R3
4.7kΩ
R4
22nF
22nF
(PS0 & PS1 NOT PRESENT ON ALTRONICS ENCODER)
FOR ENCODER TYPE 1 (Simple Grey Code per click): FIT R3 & R4
FOR ENCODER TYPE 2 (One complete cycle of Grey Code per click): FIT R1 & R4
FOR ENCODER TYPE 3 (Three changes in phase per click): FIT R2 & R3
DSP Crossover
Front Panel circuit

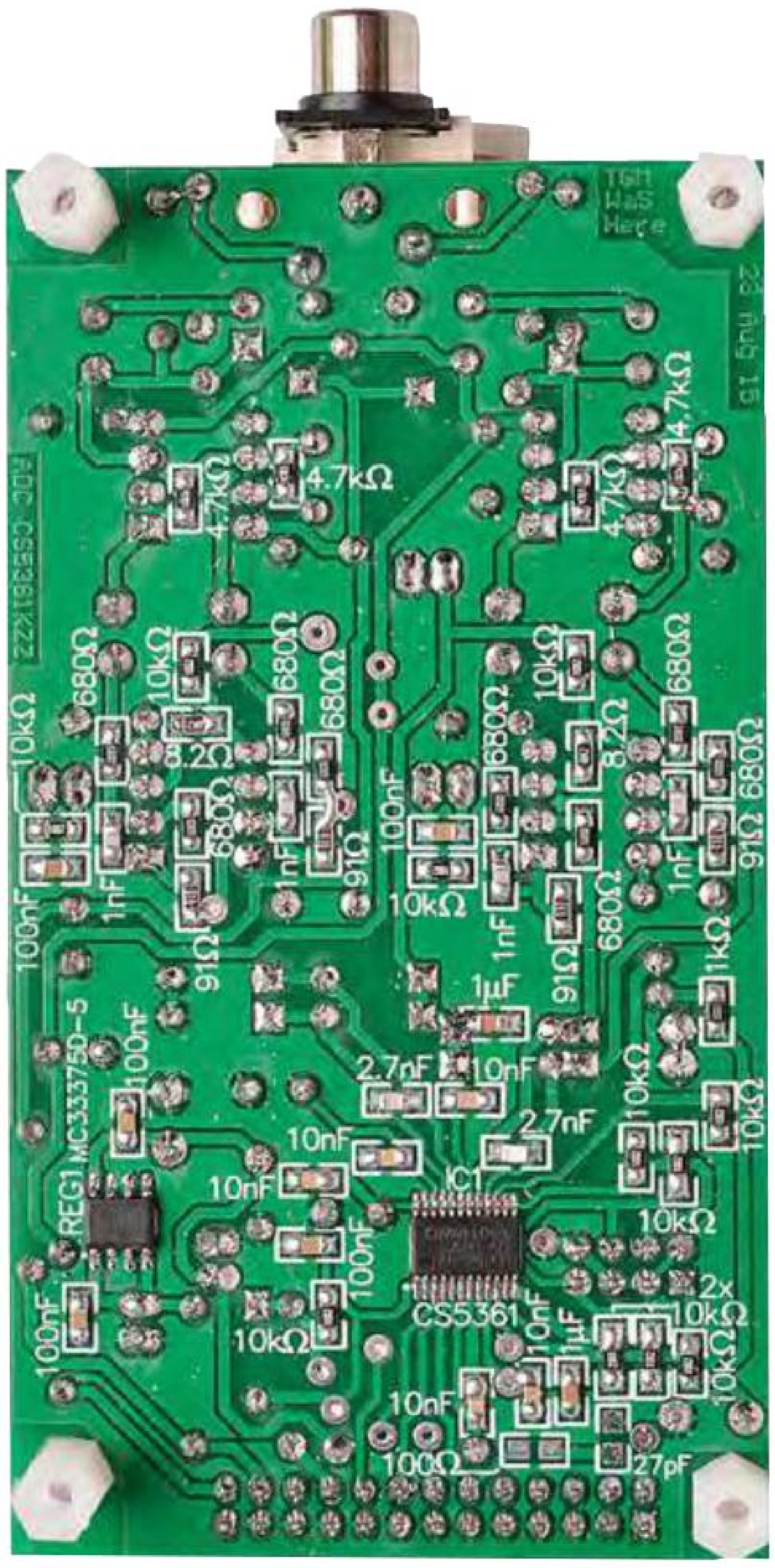
Fig.8: the front panel circuit is elementary. Two momentary pushbuttons and a quadrature (incremental) rotary encoder to CON20, which is wired back to the signal routing board and then onto the PIC32. Different combinations of resistors R1-R4 are fitted so that the CPU knows what sort of signals to expect from the rotary encoder. The two capacitors help to debounce the encoder's digital outputs.



TOP OF BOARD

UNDERSIDE OF BOARD

Fig.9: the ADC board has components on both sides; SMDs on the bottom and through-hole components on the top. Be careful with the polarity of the ICs, REG1, D1-D13 and the electrolytic capacitors. Note that diodes D1-D12 do not all face in the same direction...



... and here's the underside photo to assist you with construction (the top side was shown last month). The use of IC sockets is optional but highly recommended – just in case, just in case!

properly lined up, then tack down the pin in the opposite corner.

Next, spread a thin smear of flux paste over all the pins, then load your soldering iron tip with a little solder and run it along the pins on one side. Stop and add more solder if you are running out and repeat until there is enough solder on all pins. Don't worry if some are bridged; we'll clean that up later. Repeat for the other side.

Now add more flux paste to any areas where you suspect there may be bridges and apply some solder wick. Wait for the flux to smoke and the solder to reflow into the wick before sliding it away from the IC. Repeat for any suspected bridges, then clean that area of the board using flux residue remover, isopropyl alcohol or methylated spirits and inspect it under magnification.

Again using a magnifier, make sure there is solder from each pin to the pad below and that none are bridged. Add a little flux and then a dab of solder to any pins which do not appear to be soldered properly. Use the procedure described above to remove any bridges. Clean and re-inspect until you are happy that all the solder joints are good.

Now move on to REG1, which has much bigger and more widely spaced pins. Use a similar procedure to solder it in place, again ensuring that its pin 1 dot is oriented correctly, ie, on the side facing the DIL header.

Now move onto the SMD resistors and capacitors. You can use a similar procedure – load one pad with a little solder, slide the part in place while heating that solder, check its orientation, then wait for the first joint to solidify and solder the opposite side of the part to its pad. Add a dab of flux paste to the first pad and touch it with your soldering iron to reflow that joint and ensure it is nice and smooth.

Note that some capacitors are specified as C0G/NP0 types. These are important to obtain good audio quality as they are far more linear than X5R, X7R or Y5V dielectrics. Similarly, some resistors are thin-film types (as opposed to the cheaper thick-film types). Again, these are more linear and will give better audio performance. In both cases, fit them where shown in Fig.9.

Through-hole components

Now flip the board over and start fitting the axial through-hole components, starting with the three resistors, then the 13 diodes. Be careful that the diode cathode stripes face as shown in Fig.9, noting that many of them face in different directions, and make sure D13 is the larger type.

Follow with the ferrite beads; if yours are just loose beads, feed diode lead off-cuts through them and then bend them to suit the pad spacings and solder them in place.

Next, solder the IC sockets in place and make sure they are oriented as shown. You could solder the ICs directly to the board, which would give better long-term reliability, but that would make it harder to swap the chips over in future if you needed to do that.

Now fit the ceramic capacitors. The 100nF multi-layer types are shown in blue in Fig.9, while the others are shown in yellow. Follow with the electrolytic capacitors, ensuring that in each case, the longer lead goes through the pad marked with a '+' symbol. You may need to bend the leads in some cases to match the hole spacings on the PCB.

Next mount the headers for CON2 and JP1-JP4. You can snap these from a longer dual-row pin header strip. Make sure they have been pushed down fully before soldering the pins.

We soldered the clipping LED (LED1) directly to the board, but you could fit a 2-pin header instead, and run leads to a front panel clip indicator LED. Either way, the longer anode lead should be connected to the pad marked 'A' on the PCB.

The last part soldered to the board is CON1, the dual vertical RCA socket. We found that we had to use a 2.5mm drill bit, turned by hand, to slightly elongate the holes for the plastic posts before it would fit into the board. This has the advantage (compared to specifying larger holes on the PCB), of ensuring a very tight fit which provides good mechanical anchoring for the sockets.

Once you've pushed the sockets into their mounting holes (be careful not to break the plastic), solder the three pins. You can then plug op amps IC2-IC5 into their sockets, and shorting blocks JP1-JP4 into position, and this board is complete.

Moving on to the DAC board

Two identical stereo DAC boards are required to provide the four audio outputs in this project. You can assemble them one at a time or in parallel. The overlay diagram for this PCB is shown in Fig.10(a). It's another double-sided board, coded 01106192 and measuring 55 × 101mm.

This time, there are no components on the bottom side, but there is a mixture of SMD and through-hole components on the top. The version on the right, Fig.10(b), shows IC10 and its associated components fitted. But those are not required for this project, so build the version at left.

Once again, start by fitting the sole fine-pitch IC to the board. IC6 is in a 28-pin TSSOP package. Use the same procedure as described above, for IC1 on the ADC board.

Then solder all the SMD resistors and capacitors, again using the same procedure as before.

Note that all the SMD capacitors with values below 100nF should be C0G types and many of the resistors are thin film types, again for linearity, to provide low distortion.

The two 0Ω resistors are soldered across pads 9 and 11, and 14 and 16 of IC10's footprint, so that the audio bypasses this chip and goes straight to the output.

Be careful to avoid shorting these pins to pins 10 and 15 in between, as those connect to ground, so you won't get any output on that channel if there is a solder bridge.

You can now fit the through-hole axial components, ie, the remaining resistors and the ferrite beads, followed by the IC sockets for IC7-IC9. Be careful with the orientation of these sockets as they don't all face in the same direction.

Next, mount the single through-hole ceramic capacitor, followed by the electrolytics, again taking care to ensure that the longer leads go to the pads marked '+'. Then fit DIL header CON3, followed by dual RCA socket CON4. Again, you will probably have to slightly enlarge the bigger PCB mounting holes to get the socket to fit into the board.

Plug the op amps into the sockets, making sure each pin 1 dot lines up with the notch in the socket (check Fig.10 if you're unsure) and the DAC boards are finished.

You can then move onto the power supply and signal routing board.

Power supply board assembly

There are no SMDs on this board. It's built on a double-sided PCB, coded 01106194, and which measures 103.5 × 84mm.

Overlay diagram Fig.11 shows where the components go.

Start by fitting the resistors as shown, then the diodes, which are all 1N4004 types. But they face in different directions, so check carefully to make sure the cathode stripes are oriented as shown in Fig.11.

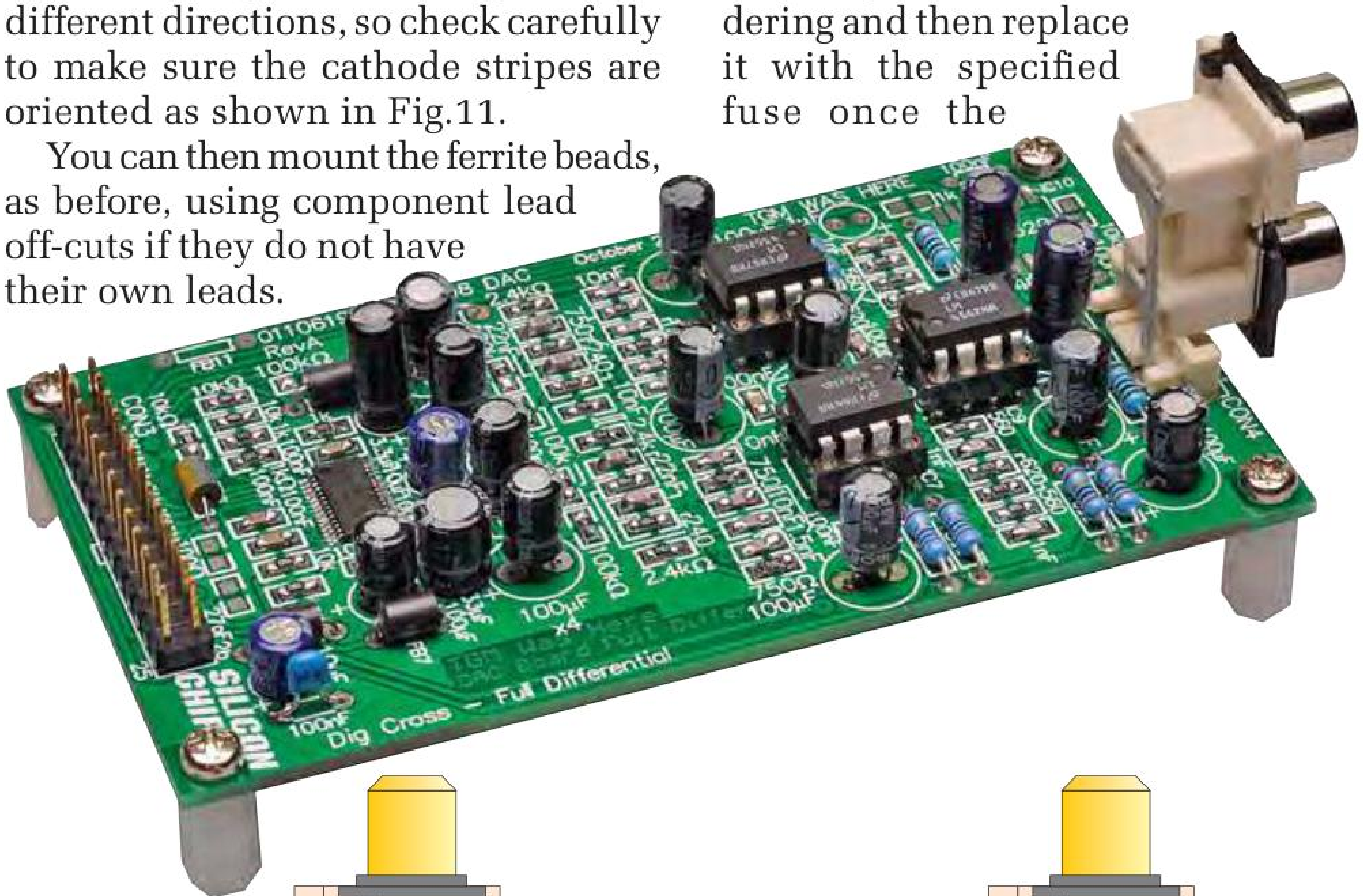
You can then mount the ferrite beads, as before, using component lead off-cuts if they do not have their own leads.

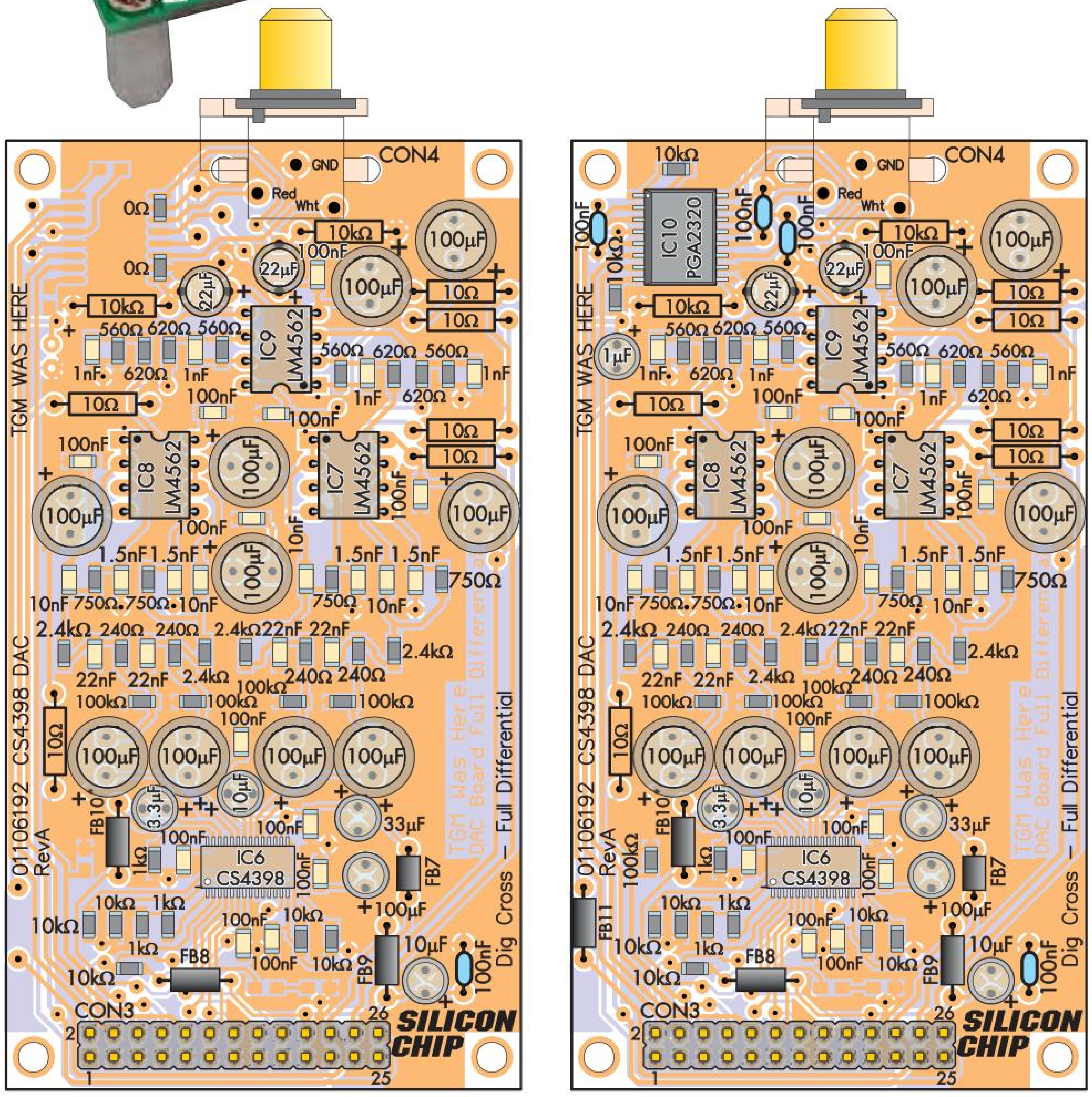
You can also use a component lead off-cut instead of the 0Ω resistor.

Then fit the pin headers, ensuring that each one is pushed down fully before soldering. As mentioned earlier, these can be snapped from longer dual-row headers, as long as they are snappable types. Follow with the ceramic capacitors, then the electrolytic capacitors. In each case, the longer lead goes into the pad marked with a '+' sign.

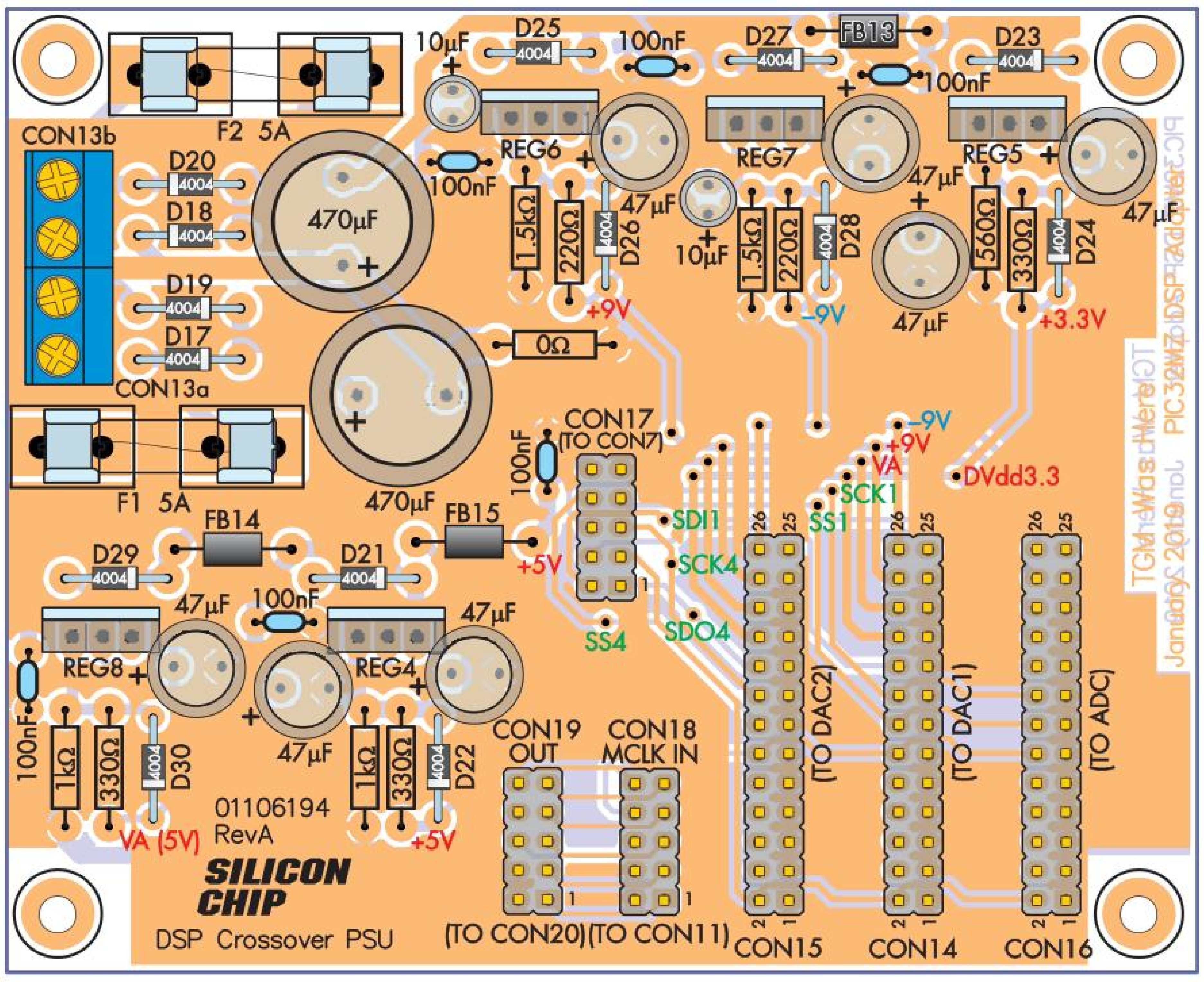
Now solder the four fuse clips in place, with the fuses clipped into each pair to ensure that the retaining tabs are on the outside and that they line up properly.

Ideally, use a blown fuse while soldering and then replace it with the specified fuse once the





Figs.10a (left) and 10b (right): unlike the ADC board, this DAC board has a mixture of through-hole and SMD components on the top side, and no components on the bottom side. The version at the left is what's required for this project; the version at right has optional volume control IC10 fitted.



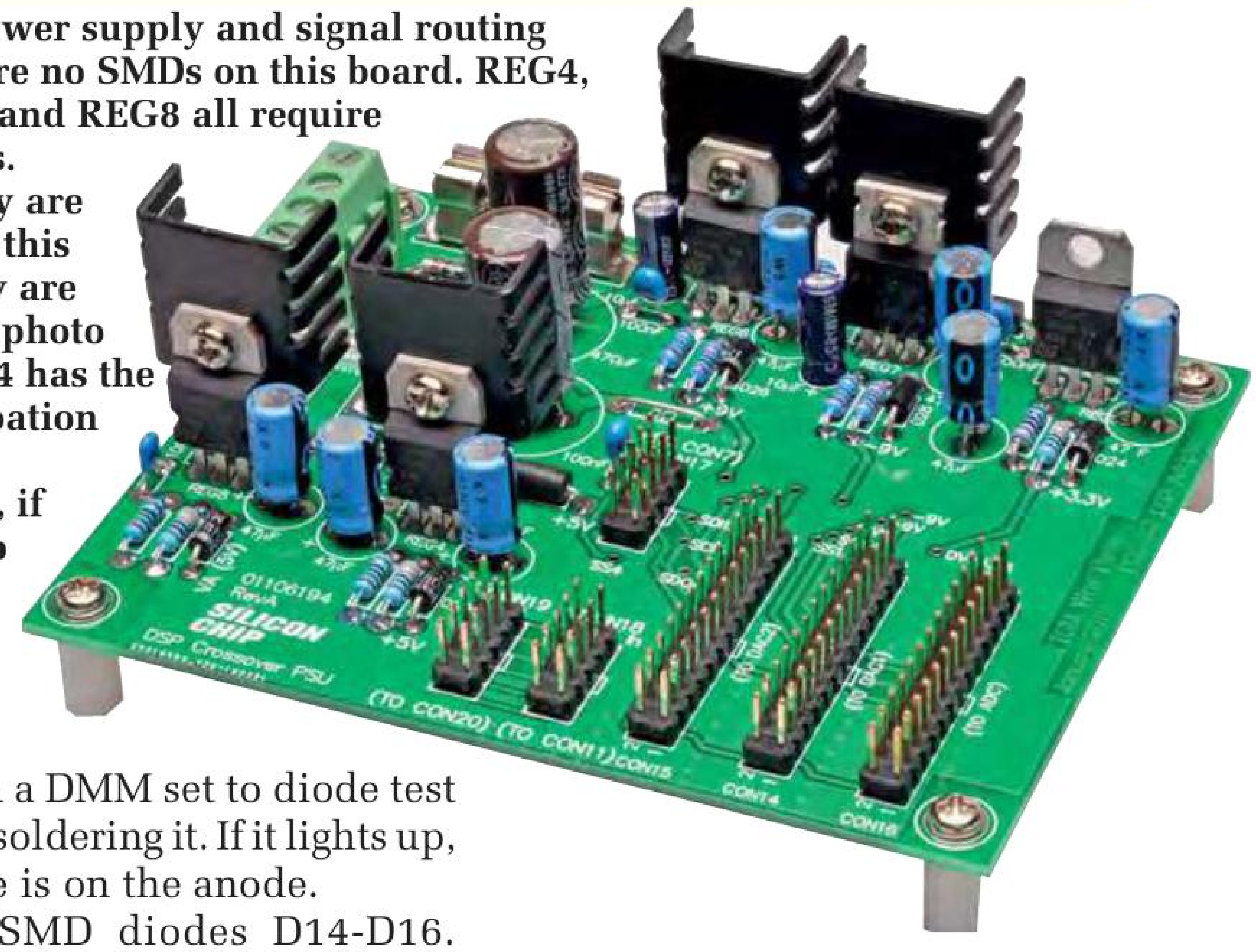


Fig.11: the power supply and signal routing PCB. There are no SMDs on this board. REG4, REG6, REG7 and REG8 all require flag heatsinks. Although they are not shown in this diagram, they are shown in the photo at right. REG4 has the highest dissipation so fit a larger heatsink to it, if possible. Also note the various test points.

clips have cooled down. You will need quite a hot iron to get the solder to flow well, and use a generous amount.

Next, dovetail the two 2-way terminal blocks together (if you don't have a 4-way block) and solder it with the wire entry holes facing the edge of the board.

Before fitting the regulators, consider how you are going to mount the heatsinks. We used 6021-type flag heatsinks, but mounted them upside-down to avoid fouling components around the regulators, because we had pushed the TO-220 packages all the way down before soldering them.

We think that this will also reduce temperatures on the board, because it keeps the fins away from the board, and allows cooling air to more easily circulate. However, if you want to fit flag heatsinks 'right-way-up', you could do so by fitting them to the regulators first before pushing them down, then lifting them slightly before soldering the leads.

Note that REG4, which supplies 5V to the CPU board and for the LCD, has quite high dissipation.

If you can fit a bigger heatsink than specified to this regulator, that would be even better. But the 6021-type should be adequate. REG5 does not need a heatsink as its dissipation is quite low.

Having sorted out the heatsinking, fit the five regulators. REG7 is the LM337 negative type; the other four are all LM317s, so don't get them mixed up.

Once the regulators and heatsinks are installed, the power supply board is finished and you can move onto the last major board, which hosts the main CPU.

CPU board assembly

This board is smaller and has mostly SMD components. It's built on a double-sided PCB, coded 01106193, and which measures 60.5 × 62.5mm. Fig.12 shows where the components go.

Start with the CPU (IC11) which is in a 64-pin quad flat pack. Its pin pitch is slightly larger than for the TSSOP, but it has pins on all four sides. Use the same basic technique, but make sure that the pins on all four sides are properly lined up on their pads before soldering more than one pin. Follow with IC12, an 8-pin SOIC package device, which is a much simpler affair.

Then move onto the SMD capacitors and resistors, followed by LED2. SMD LEDs typically have a green dot or marking to indicate the cathode, and this is on the opposite side from the anode, which goes to the pad marked 'A' on the PCB. But it's best to check the LED with a DMM set to diode test mode before soldering it. If it lights up, the red probe is on the anode.

Next, fit SMD diodes D14-D16. These are schottky diodes in a MELF cylindrical package. We used 'SMA' (DO-214AC) package diodes on our prototype, but they barely fit on the provided pads and are much trickier to solder. The MELF diodes will be much easier. Like through-hole diodes, they have a stripe at the cathode end and this must be oriented as shown in Fig.12.

Now you can solder ferrite bead FB12 in place, followed by pin headers CON7-CON11 and CON23. There is no need to fit a header for CON12. You can also now fit the pin headers for LK1, LK2 and JP5, followed by optional screw terminal block CON5, with its wire entry holes towards the nearest edge of the board.

Next, mount crystals X1 and X2, taking care to avoid putting too much stress on the leads as they are relatively thin. Gently bend them to fit the pad spacings.

If using a large (HC-49-style) crystal for X2, fit an insulating washer underneath it so that its metal can won't short on any of the components below, since the leads may not be stiff enough to hold it firmly in place without resting on them.

You can then install trimpot VR1, with its adjustment screw positioned as shown, followed by the electrolytic capacitors, with their longer leads to the pads marked '+'.

Solder REG2 and REG3 in place, with the metal tabs oriented as shown. Don't get them mixed up as they are different types – REG3 is a standard LM317 adjustable regulator, while REG2 is a special low-dropout type. Neither requires a heatsink.

Finally, insert the jumper shunts for LK1, LK2 and JP5, as shown in Fig.12.

Front panel and LCD assembly

This board has just a few components and is fitted just behind the unit's front panel, next to the LCD, allowing the rotary encoder shaft and pushbuttons to poke through holes drilled in that panel. It's built on a double-sided PCB measuring 107.5 x 32.5mm. The PCB overlay diagram is shown in Fig.13.

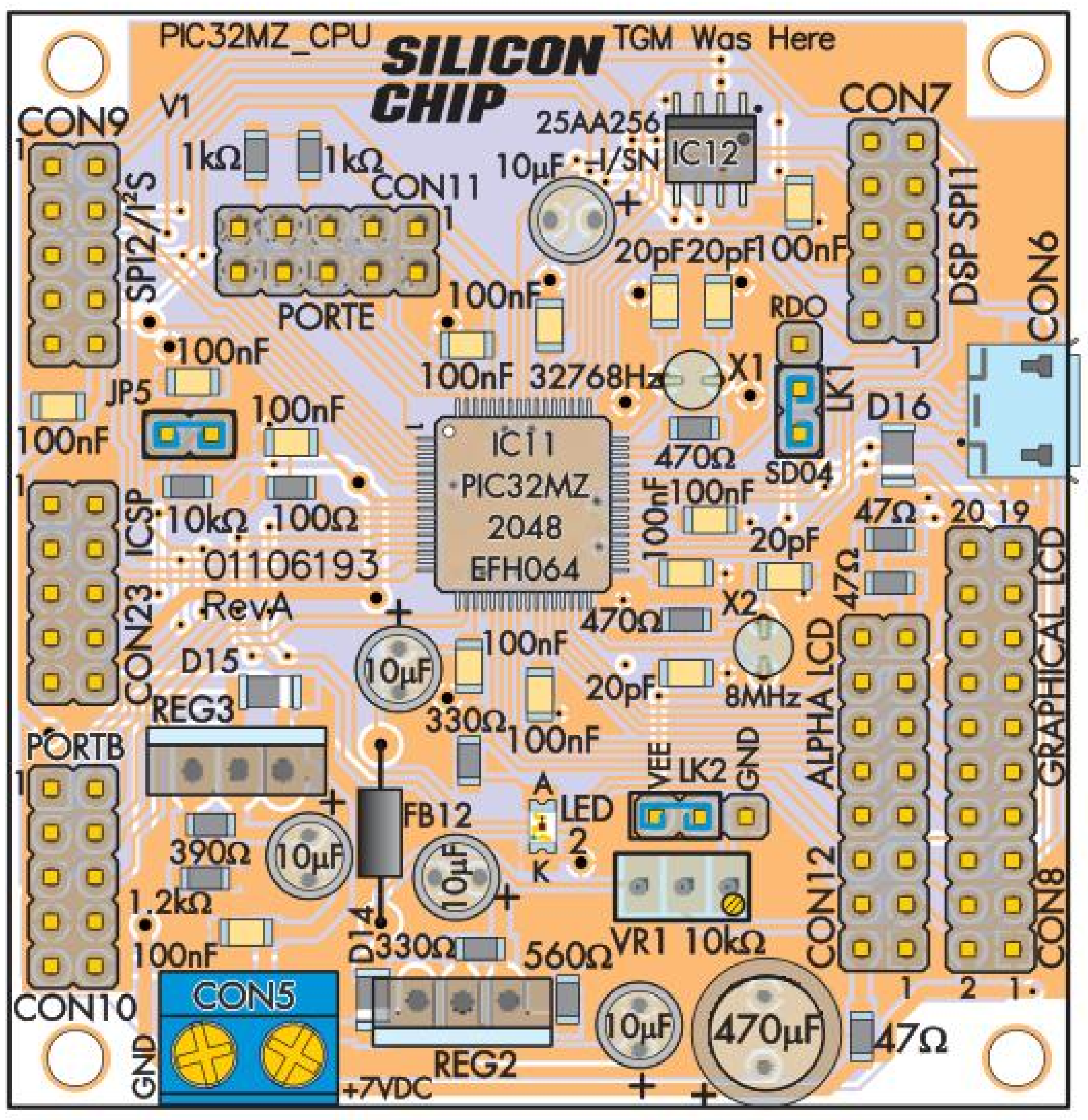

PIC32MZ_CPU
SILICON CHIP
TGM Was Here
CON9
CON7
CON11
PORTE
IC12
25AA256
X1
LK1
D16
CON6
DSP SPI1
SPI2/I2S
JP5
ICSP
PIC32MZ 2048 EFH064
01106193
RevA
CON23
D15
REG3
X2
ALPHA LCD
GRAPHICAL LCD
PORTB
FB12
LED
LK2
VR1 10kΩ
CON12
CON8
CON10
CON5
D14
REG2
GND
+7VDC
470μF

Fig.12: the CPU board uses mostly SMD parts, but there are also some through-hole parts and connectors, all on the top side. Note the orientation of IC12, IC13 and MELF diodes D14-D16. The jumpers for LK1, LK2 and JP5 are shown in their normal operating positions for this project.

Start by fitting the resistors. Four are shown in Fig.13, but only two are fitted, as shown on the circuit diagram, Fig.8. For the Altronics S3350 rotary encoder, fit R1 and R4. For the Jaycar SP0721 encoder, fit R2 and R3.

Follow with the two 22nF capacitors, which should either be fitted to the underside of the board, as shown in Fig.13, or laid over on the top side of the board, so they will clear the front panel. Then solder the 10-pin DIL header in place, on the underside of the board.

That just leaves the rotary encoder and pushbutton(s). As explained earlier, if you're using the Jaycar rotary encoder (or an equivalent), it has an integral pushbutton, so you don't need to fit S2. You can still fit S2 if you want; it will merely provide an alternative way to use the SELECT function.

Also keep in mind that if you use the Jaycar encoder, this board is then mounted directly to the front panel of the unit.

But if you fit the Altronics encoder in the usual manner, ie, with its shaft parallel to the PCB, you would need to mount it differently, and that would probably require S1 and S2 to be mounted directly on the front panel and wired back to this board (two wires required for each).

To avoid that, you could bend RE2's three pins down and mount it vertically on the board, like RE1. You would need to solder stiff wire to its two mounting lugs, bend these over under the board and attach them to the mounting holes using a generous amount of solder, to provide sufficient mechanical strength.

Once RE1/RE2 and S1/S2 are in place, this board is finished.

Building the LCD adaptor

The LCD has a 20-pin SIL header, but it is connected to the CPU board via a 10×2 pin DIL header and DIL IDC connectors. So we have designed a small adaptor board to make this a 'plug and play' affair. It's coded 01106196, measures 51 × 13mm and is shown in Fig.14. The only parts on this board are the SIL and DIL headers.

Most LCD screens have a 20-pin header with pin 1 (Vss/GND) at right (looking at the LCD screen with the connector at the bottom) and pin 20 (K–) at left. If your screen has a different pinout then you will need to come up with a different connecting arrangement.

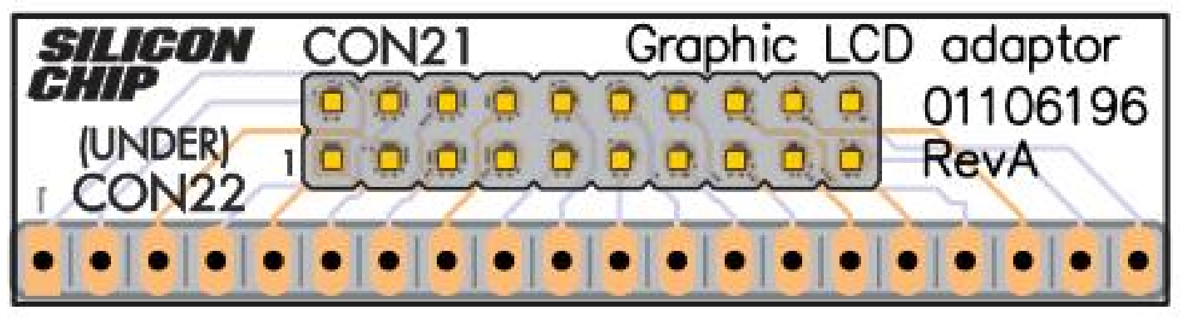

SILICON CHIP
CON21
Graphic LCD adaptor
01106196
RevA
(UNDER)
CON22

Fig.14: the LCD adaptor is dead simple and just connects pins 1-20 of DIL header CON21, mounted on the top side, to pins 1-20 of SIL header CON22, on the other side of the board. You could use a header socket for CON22, but it will be more reliable if you solder it to the LCD pin header.

Start by soldering a 20-pin SIL header to the LCD, on the back of the board (ie, the opposite side to the LCD screen), with the longer pins projecting out the back. Then solder the DIL pin header to the top side of the adaptor board, as shown in Fig.14.

You can then place this adaptor board over the pin header sticking out the back of the LCD, making sure that its pin 1 at left lines up with pin 1 on the LCD. Solder all 20 pins.

Making up the cables

You will need seven interconnecting cables to complete the unit, and

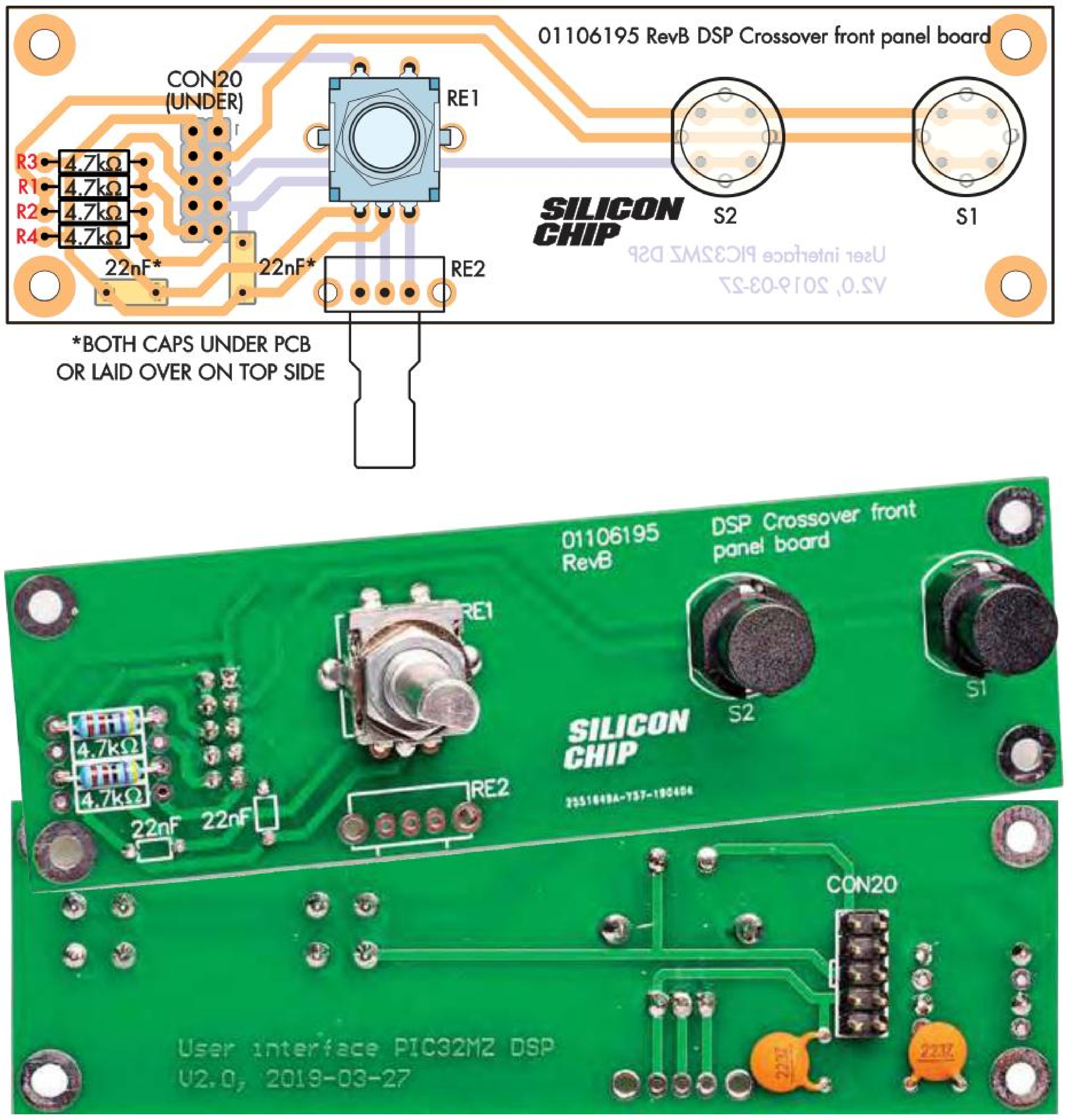

01106195 RevB DSP Crossover front panel board
CON20 (UNDER)
RE1
R3
R1
R2
R4
4.7kΩ
22nF*
RE2
SILICON CHIP
S2
S1
User interface PIC32MZ DSP
V2.0, 2019-03-27
*BOTH CAPS UNDER PCB OR LAID OVER ON TOP SIDE

Fig.13: the front panel PCB. Note that only one of RE1 (Jaycar SR1230) or RE2 (Altronics S3350) is fitted and in the case where RE1 is used, pushbutton S2 is redundant and may be left off. Also, if RE1 is fitted, fit resistors R2 and R3; if RE2 is fitted, fit resistors R1 and R4.

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PARTS LISTS

Stereo ADC input board

1 double-sided PCB coded 01106191, 55.5 x 102mm
1 dual vertical RCA socket (CON1)
1 13x2 pin header (CON2)
4 8-pin DIL IC sockets (for IC2-IC5)
1 4x2 pin header (JP1-JP4)
4 jumper shunts (JP1-JP4)
6 ferrite beads (FB1-FB6)

Semiconductors
1 CS5361-KZZ or CS5381-KZZ high-performance stereo ADC, TSSOP-24 (IC1)**
4 NE5532 dual low-noise op amps, DIP-8 (IC2-IC5)
1 MC33375D-5.0R2G SMD low-dropout linear regulator, SOIC-8 (REG1)**
1 5mm red LED (LED1)
12 BAT85 schottky diodes (D1-D12)
1 1N4148 small signal diode (D13)

Through-hole capacitors
3 220µF 10V electrolytic
6 47µF 25V electrolytic
2 22µF 50V electrolytic
4 10µF 50V electrolytic
1 1µF 50V electrolytic
10 100nF 50V multi-layer ceramic
2 100pF C0G/NP0 ceramic
2 33pF C0G/NP0 ceramic

SMD capacitors (all 2012/0805 X7R unless otherwise stated)
2 1µF 6.3V
5 100nF 50V
5 10nF 50V
2 2.7nF 50V C0G/NP0 5%
4 1nF 50V C0G/NP0 5%

Resistors (all SMD 2012/0805 1% unless otherwise stated)
2 100kΩ through-hole 1/4W 1% metal film
11 10kΩ
4 4.7kΩ thin film*
1 1kΩ
8 680Ω or 681Ω thin film*
4 91Ω thin film*
2 8.2Ω
1 5.1Ω through-hole 1/2W 1% or 5%

Stereo DAC output board (per board, two required)

1 double-sided PCB coded 01106192, 55 x 101mm
1 13x2 pin header (CON3)
1 dual vertical RCA socket (CON4)
3 8-pin DIL IC sockets (for IC7-IC9)
4 ferrite beads (FB7-FB10)

Semiconductors
1 CS4398-CZZ high-performance stereo DAC, TSSOP-28 (IC6)**
3 LM4562 dual ultra-low-distortion op amps, DIP-8 (IC7-IC9)**
1 PGA2320IDW stereo volume control chip, SOIC-16 (IC10; optional - see text)**

Through-hole capacitors
11 100µF 16V electrolytic
1 33µF 25V electrolytic
2 22µF 50V electrolytic
2 10µF 50V electrolytic
1 3.3µF 50V electrolytic
1 100nF 50V multi-layer ceramic

SMD capacitors (all 2012/0805 50V ceramic)
12 100nF X7R
4 22nF C0G/NP0 5%
4 10nF C0G/NP0 5%
4 1.5nF C0G/NP0 5%
4 1nF C0G/NP0 5%

Resistors (all SMD 2012/0805 1% unless otherwise stated)
2 10kW through-hole 1/4W 1% metal film
5 100kΩ
5 10kΩ
4 2.4kΩ or 2.43kΩ thin film*
3 1kΩ
4 750Ω thin film*
4 620Ω thin film*
4 560Ω thin film*
4 240Ω thin film*
6 10Ω through-hole 1/4W 1% metal film
2 0Ω

Extra parts needed if IC10 is fitted
1 ferrite bead (FB11)
1 1µF 50V electrolytic capacitor
3 100nF 50V multi-layer ceramic through-hole capacitors
1 100kΩ SMD 2012/0805 1% resistor
2 10kΩ SMD 2012/0805 1% resistors

CPU board

1 double-sided PCB coded 01106193, 60.5 x 62.5mm
1 2-way mini terminal block, 5.08mm spacing (CON5; optional)
5 5x2 pin headers (CON7,CON9-CON11,CON23)
1 10x2 pin header (CON8)
2 3-pin headers (LK1,LK2)
1 2-pin header (JP5)
3 shorting blocks (LK1,LK2,JP5)
1 ferrite bead (FB12)
1 32768Hz watch crystal (X1)
1 miniature 8MHz crystal (X2) OR
1 standard 8MHz crystal with insulating washer (X2)
1 10kΩ vertical trimpot (VR1)

Semiconductors
1 PIC32MZ2048EFH064-250I/PT 32-bit microcontroller programmed with 0110619A.HEX, TQFP-64 (IC11)
1 25AA256-I/SN 32KB I^{2}C EEPROM, SOIC-8 (IC12)**
1 LD1117V adjustable 800mA low-dropout regulator, TO-220 (REG2)
1 LM317T adjustable 1A regulator, TO-220 (REG3)
1 blue SMD LED, SMA or SMB (LED2)
3 LL5819 SMD 1A 40V schottky diodes, MELF (MLB) (D14-D16)

Capacitors
1 470µF 10V electrolytic
5 10µF 50V electrolytic
11 100nF SMD 2012/0805 50V X7R
4 20pF SMD 2012/0805 50V C0G/NP0

Resistors (all SMD 2012/0805 1%)
1 10kΩ
2 470Ω
2 330Ω
1 1.2kΩ
1 560Ω
1 100Ω
2 1kΩ
1 390Ω
3 47Ω

Power supply/routing board

1 double-sided PCB coded 01106194, 103.5 x 84mm
4 M205 fuse clips (F1,F2)
2 5A M205 fast-blow fuses (F1,F2)
3 ferrite beads (FB13-FB15)
2 2-way terminal blocks, 5.08mm pitch (CON13)
3 13x2 pin headers (CON14-CON16)
3 5x2 pin headers (CON17-CON19)
4 6021 type mini-U TO-220 heatsinks (for REG4 and REG6-REG8) [Jaycar HH8504, Altronics H0635]

Semiconductors
4 LM317T adjustable 1A regulators, TO-220 (REG4-REG6,REG8)
1 LM337T adjustable -1A regulator, TO-220 (REG7)
14 1N4004 400V 1A diodes (D17-D30)

Capacitors
2 470µF 16V electrolytic
7 47uF 25V electrolytic
2 10uF 50V electrolytic
6 100nF 50V through-hole multi-layer ceramic

Resistors (all 1/4W 1% metal film)
2 1.5kΩ
3 330Ω
2 1kΩ
2 220Ω
1 560Ω

Front panel interface

1 double-sided PCB coded 01106195, 107.5 x 32.5mm
1 5x2 pin header (CON20)
2 4.7kΩ 1/4W through-hole resistors
2 22nF through-hole ceramic capacitors
2 PCB-mount snap-action momentary pushbuttons (S1,S2)* [Jaycar SP0721, Altronics S1096]

1 3-pin rotary encoder (RE1/RE2) [eg, Altronics S3350 or Jaycar SR1230 with integrated pushbutton]
1 knob (to suit RE1/RE2)
* only one required if using Jaycar SR1230 encoder

LCD assembly

1 128 x 64 pixel graphical LCD with 20-pin connector
1 double-sided PCB, coded 01106196, 51 x 13mm
1 10x2 pin header
1 20-pin header

Chassis parts, connecting cables etc

1 2U rackmount case or similar
1 M205 'extra safe' fuseholder
1 1A slow-blow M205 fuse
1 5A 250VAC DPST or DPDT switch
28 9mm long M3 tapped spacers
56 M3 x 5mm black panhead screws
3 No.2 x 6mm self-tapping screws
1 1m length of 26-way ribbon cable#
1 30cm length of 20-way ribbon cable#
1 1m length of 10-way ribbon cable#
6 26-pin IDC line plugs
2 20-pin IDC line plugs
6 10-pin IDC line plugs
1 1m length 10mm diameter heatshrink
10 small cable ties
4 instrument feet with mounting screws
# or 1.3m length 26-way(+) ribbon cable

Component notes

PCBs
A full set of PCBs is available from the PE PCB Service.

Resistors/semiconductors
** For example, the Yageo RT0805FRE07 or the RT0805FRE13 series available from mouser.co.uk*
***Available from Mouser or Digi-key*

Ferrite beads
Murata FSRH050050RN000B (Digi-Key 490-11952-ND)

Diodes
D14-16: Mouser part 821-LL5819L0

Display
The display is a common type of monochrome graphical LCD. It has 128 x 64 pixels and a 20-pin connector. Typical examples from aliexpress.com are parts: 2046468825, 1420941126, 32624363605, 1420941126, 32699482638

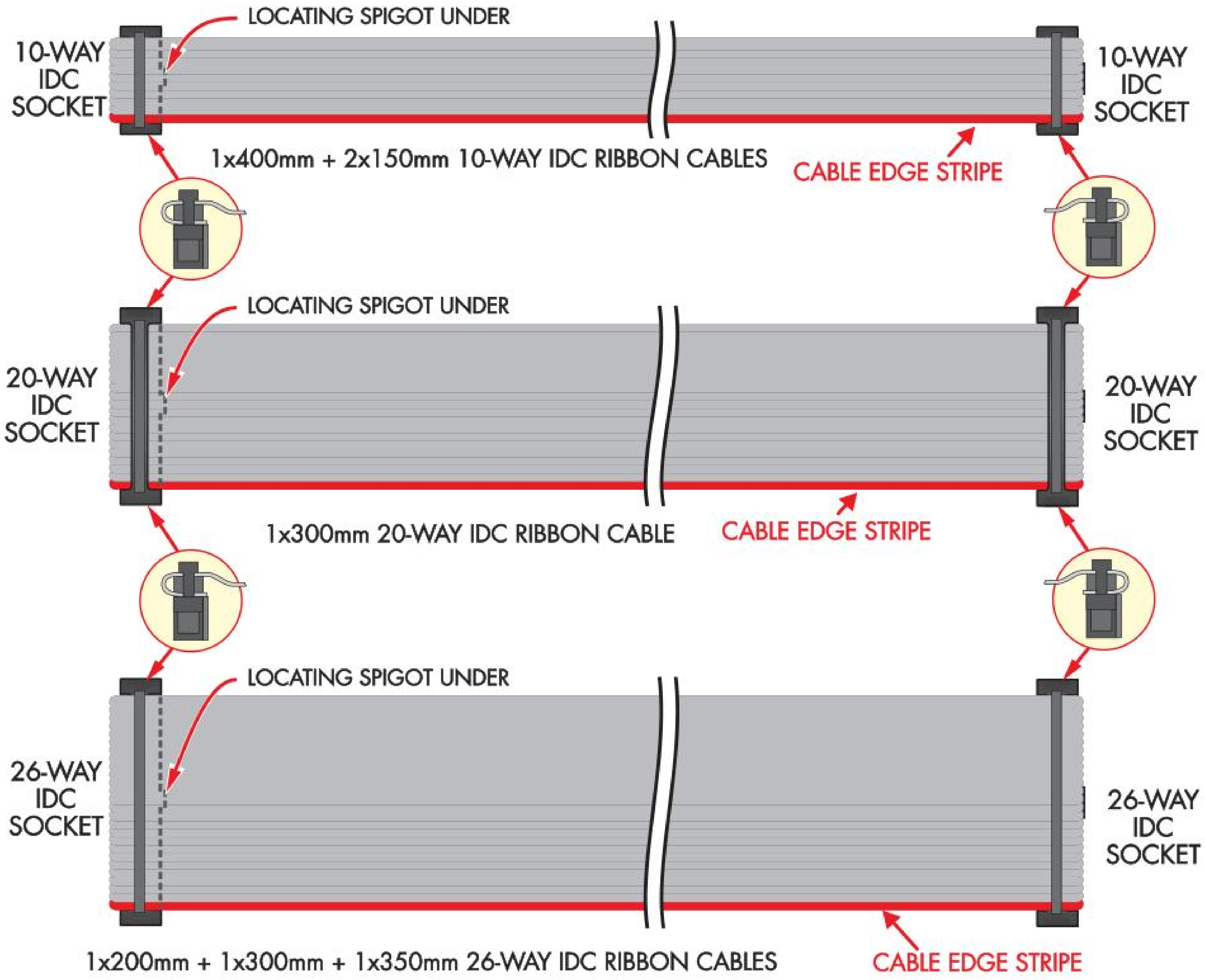

Fig.15: here's how to make up the seven ribbon cables required to connect the various boards together. Three ten-way cables are required in two different lengths, plus one 20-way cable and three 26-way cables, each a different length.

they're also handy to have for testing, so let's make them up now. These are shown in Fig.15.

There are three 10-way cables, one 40cm long and two 15cm long; one 20-way cable, 30cm long; and three 26-way cables, 20cm, 30cm and 35cm long. Cut each section of ribbon cable to length, leaving around 5cm extra in each case for crimping to the connectors.

You can strip these cables out of ribbon cables with more wires, by making a small cut between two wires and then separating the sections by pulling them apart.

It's best to use a dedicated IDC crimping tool for this job, such as Altronics T1540. You can use a vice, but you have to be careful to avoid crushing and breaking the plastic IDC connectors.

Each connector has three parts: the bottom part, which has the metal blades that cut into the ribbon cable; the middle part, which clamps the cable down onto these; and a locking bar at the top that holds it all together once it has been crimped.

Note how, as shown in Fig.15, the cable passes between the locking bar and upper part before folding over on the outside edge and then being crimped underneath.

So with this in mind, slightly separate the three pieces without actually taking them apart, and feed the ribbon cable through as shown. Ensure there is enough 'meat' for the metal blades to cut into, then place it into your crimping tool or vice without allowing the cable to fall out. Clamp the three pieces together, gently at first, then more firmly.

The trick is to crimp it hard enough to ensure that the blades cut fully through the insulation and make good contact with the copper wires, without pressing so hard that you break the plastic.

If using a vice, it's best to wedge a piece of cardboard between each end of the connector and the vice, to provide some cushioning.

Once you've crimped a connector at one end of the cable, do the one at the other end, making sure that when you're finished, the locating spigots will both be facing in the same direction – see Fig.15. Then repeat this procedure for all the other cables that are required.

Next month

The final article in this series will cover testing all of these assembled boards, programming the microcontroller and putting it all together in its case.

We'll also have some performance measurements and instructions for using the finished unit.

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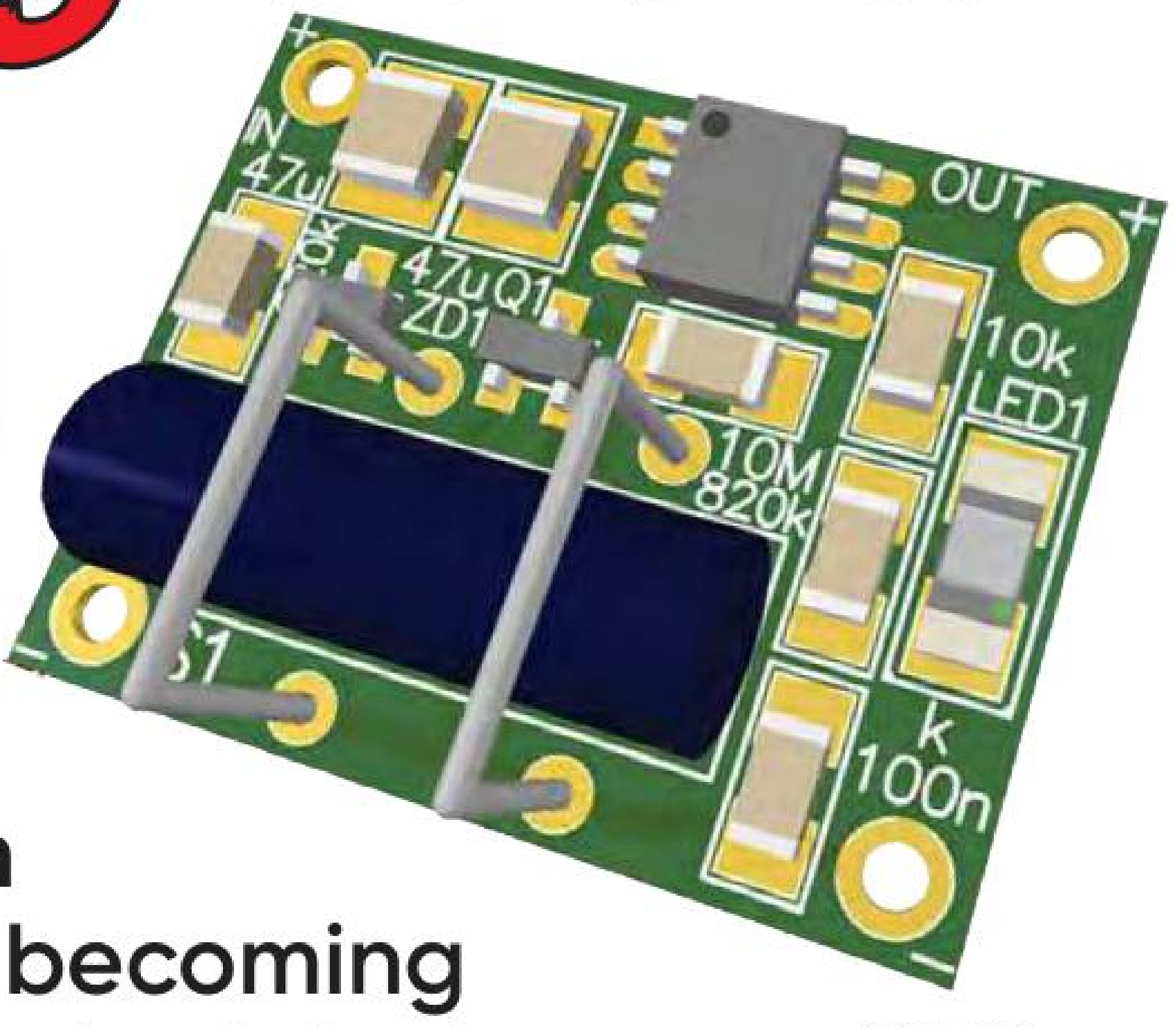
Motion-Triggered 12V Switch



This simple circuit switches on a 12V circuit when it detects acceleration or vibration. It has many uses, but it's especially handy if you have an always-on car accessory power socket. These are becoming quite common but they make it tricky to use a standard dashcam or GPS. This project solves that problem and it can be built in a couple of hours.

by Nicholas Vinen

This solves a problem that shouldn't exist – but it does, and it's really annoying. While it has many different potential uses, I designed it specifically to switch a dash-mounted video camera ('dashcam') on automatically when you start driving the car, then off again when you stop.

But, you are wondering, don't dashcams already do that? Aren't they powered on and off automatically as the accessory socket switches on and off with the vehicle ignition? Of course they are… in most cases.

The problem

But for whatever reason, the accessory power socket ('cigarette lighter') in my wife's car does not switch on and off with the ignition. Since it's always on, after driving, her dashcam runs until the car's battery is almost flat, at which point the accessory power socket shuts off.

As if that wasn't annoying enough, when (if!) you start the car the next time, it doesn't come back on automatically – very frustrating.

You have to remember to unplug and re-plug the dashcam to get it to go on. Somehow, I doubt we are the only people with this problem.

Obviously, this is not very satisfactory. I guess the power socket remains on so you can charge your phone (or run other accessories) with the ignition off. But I think this 'feature' causes more problems than it solves.

And while the socket is no doubt under the control of the body computer, I can't find any way to set it back to the old-fashioned scheme – which worked fine, thank you very much. There's no obvious physical or software switch to do so.

Hence, I had to come up with this project as a way to switch the dashcam on and off automatically, while drawing very little power when it is off, so the vehicle's battery still has a reasonable charge after sitting for a few days.

The solution

The obvious solution was to sense when the car is running via the battery voltage. But another 'feature' of this otherwise fine vehicle is that it doesn't always charge the battery while running, So I had to find another way.

My next idea was to have an accelerometer that's monitored by a low-power microcontroller, waiting for the vehicle to move before switching on power to the dashcam.

It could then leave the power on as long as the vehicle was in motion (with a timer, so it doesn't go off when you're stationary for a couple of minutes at a time), and switch it off at the end of the trip.

But I realised that I was over-complicating matters. There is a much simpler solution – using a vibration switch. These small, low-cost devices consist of a spring surrounding a metal post inside a can. At rest, the spring doesn't touch the post; but any movement or vibration causes it to come into contact, closing the switch contacts. Less sensitive versions use stiffer springs.

It's a problem that shouldn't exist; but it does if your cigarette lighter socket doesn't power off when the ignition is off!

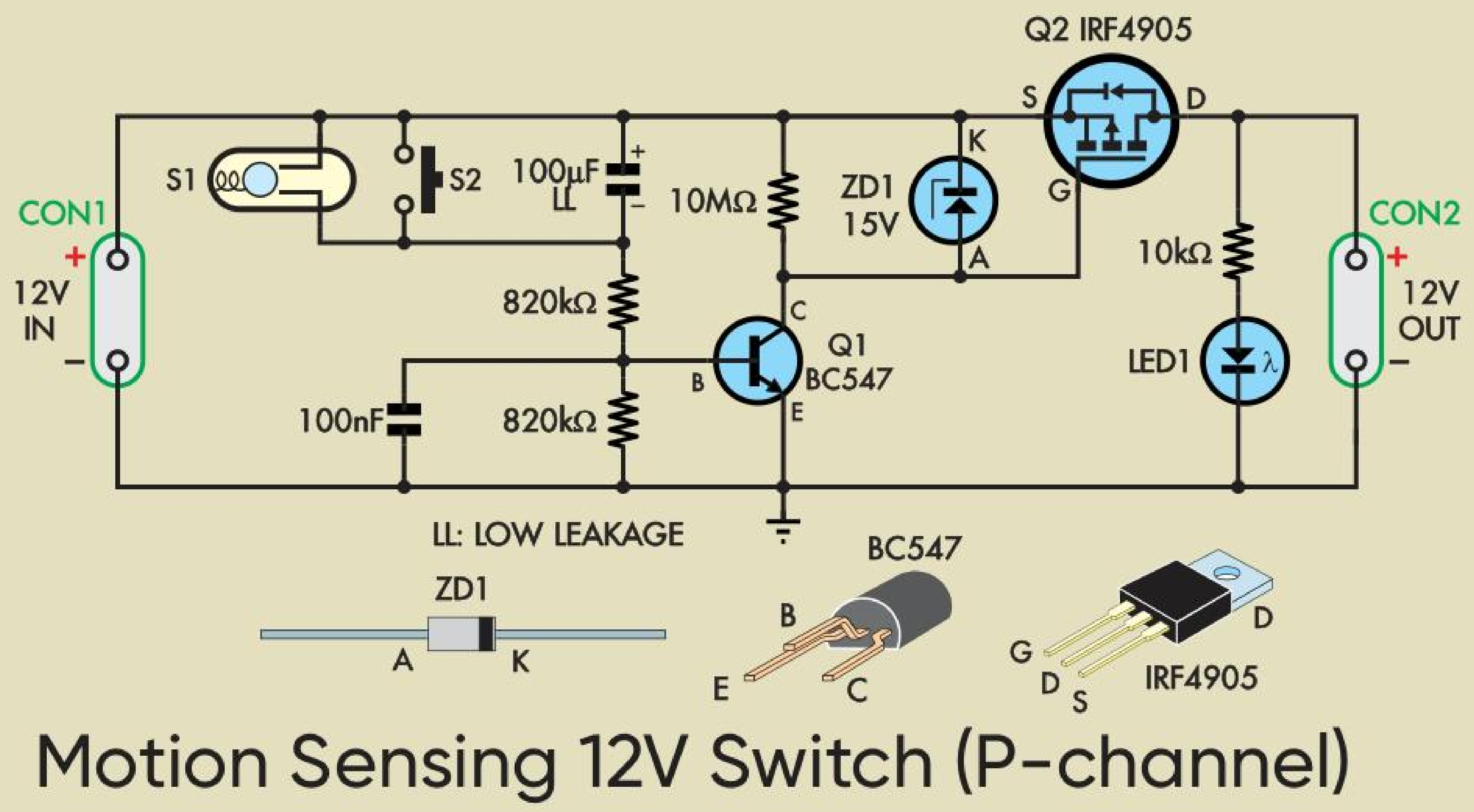


Fig.1 (left): the circuit diagram for the version of the circuit which uses a P-channel MOSFET (Q2). It has the advantage that the incoming and outgoing ground connections are continuous – power is interrupted on the positive side only.

Vibration or motion causes S1 to discharge the 100µF capacitor, which switches on Q1 and then Q2 and gives a five-minute time delay before they switch off again if S1 is not triggered in the meantime.

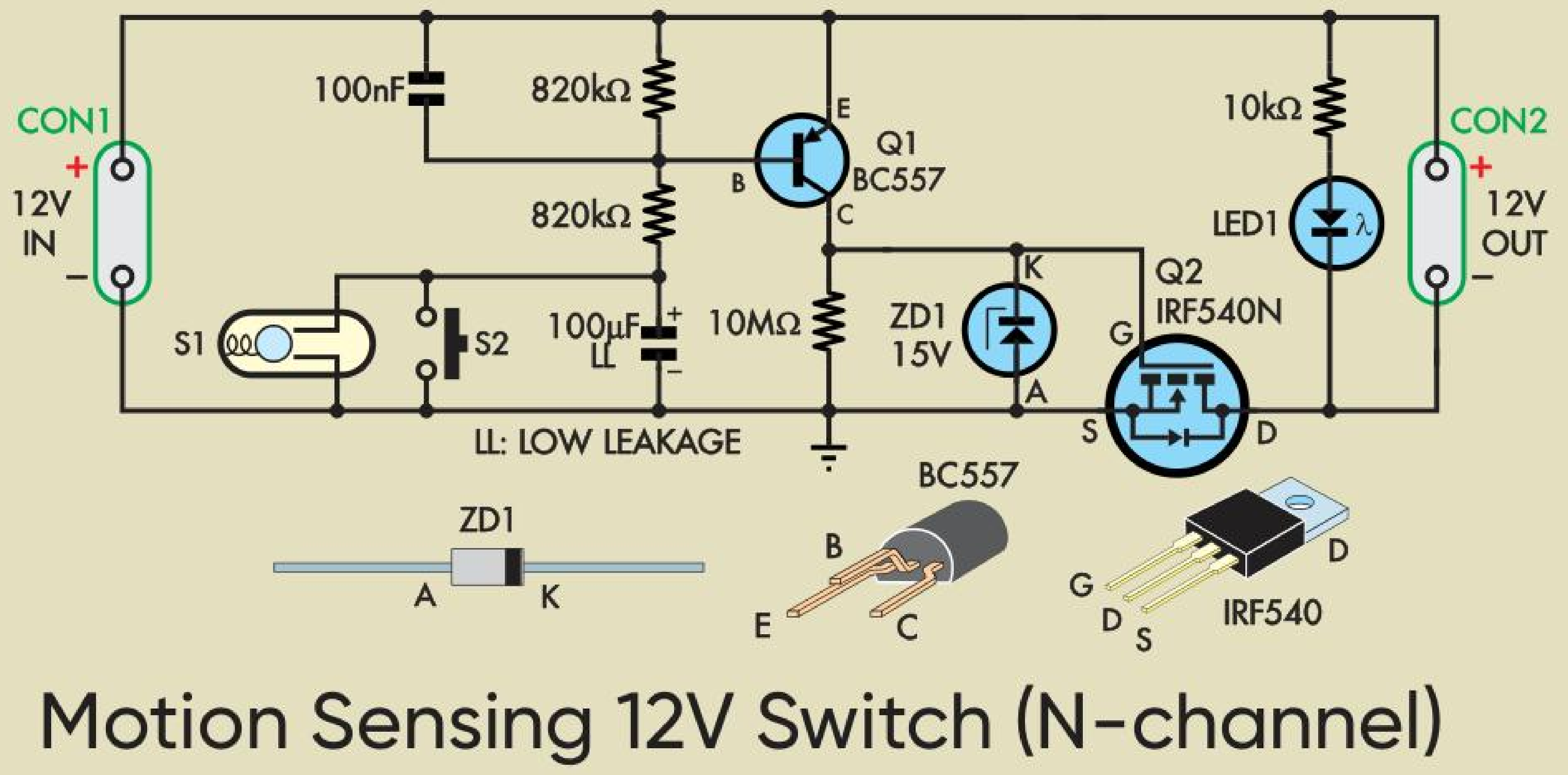


Fig.2 (right): this version of the circuit uses an N-channel MOSFET for Q2 instead. If you compare it to Fig.1, you can see that the changes essentially involve flipping everything upside-down to deal with the different gate drive polarity requirement of this MOSFET.

Otherwise, it works the same, except for the fact that it breaks the ground connection between the input and output side to switch the connected device(s) off.

So it's just a matter of using that switch to trigger a separate device to switch 12V power to the dashcam, and adding a timer to delay switch-off.

The design presented here uses just nine (mandatory) components, plus the accessory plug and socket, to achieve that. That's certainly a lot simpler than the accelerometer-based solution would have been!

I set the time-out period to about five minutes. Even in the worst traffic, you usually are not stationary for that long.

Circuit description

Refer now to the circuit diagram shown in Fig.1. This uses a P-channel MOSFET as the switch (Q2) so that it's the +12V line which is switched.

The ground connection is unbroken. This may be important in some cases, where your dashcam might connect elsewhere in the vehicle and could have a separate ground connection to the chassis.

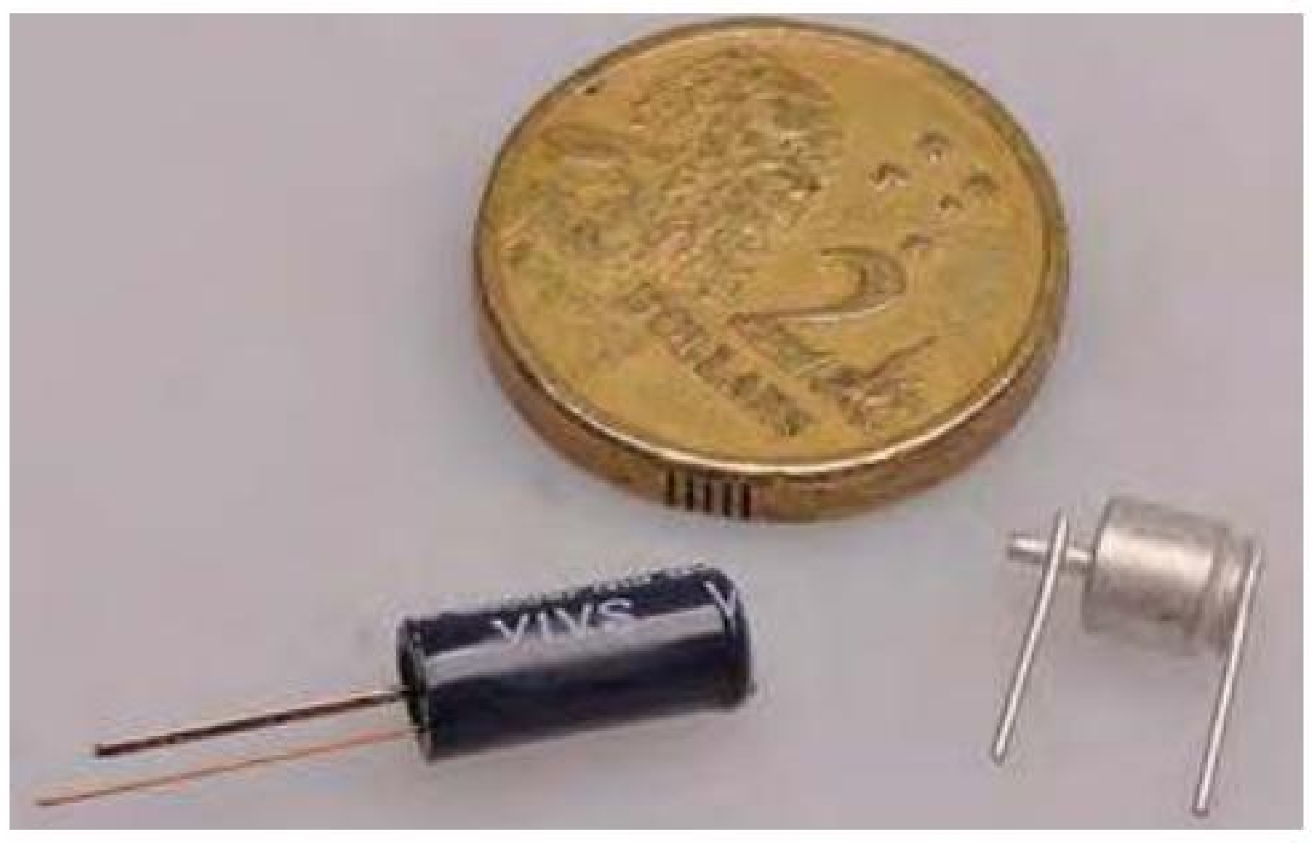
In that case, switching the negative end of the power supply wouldn't do anything useful.

The 100µF capacitor provides the five-minute delay, in combination with the two 820kΩ resistors between its negative end and ground. Initially, when power is applied, the 100µF capacitor is discharged. That means that current flows through it and the upper 820kΩ resistor, to the base of NPN transistor Q1, as it charges.

Q1 therefore switches on, pulling the gate of MOSFET Q2 low, close to 0V. As a result, Q2's channel conducts current from the 12V positive input to the 12V positive output, powering the dashcam.

The 100µF capacitor charges, and after about five minutes the base of Q1 drops below about 0.5V. Q1 then begins to switch off, allowing the gate of Q2 to be pulled up to +12V by the 10MΩ resistor, switching Q2 off.

The reason we do not have the capacitor directly on the gate of Q2 is because that would cause Q2 to switch off slowly, over about 30 seconds, due to the slow charging rate of that capacitor. During this time, the MOSFET would be in partial conduction and so it would have a high dissipation, heating up and possibly burning out. Since Q1 is a bipolar junction transistor, and its load impedance is so high, it only takes a few millivolts of change in its base voltage to go from fully on to fully off. That, in turn, allows Q2 to switch off fast, typically spending less than one second in partial conduction, so it doesn't heat up too much during switch-off.



The heart of the project is one of these tiny vibration switches, shown with a $2 coin for size reference (approx same size as a UK £1 coin). On the left is the Soyo SW-1801P from Pakronics; on the right is the CM1800-1 from element14. (See parts list for UK alternatives.)

The 100µF capacitor needs to be a low-leakage type due to the high charging impedance of 820kΩ + 820kΩ = 1.64MΩ. Otherwise, it will never fully charge and so Q2 may never switch off. Alternatively, you can use two 47µF tantalum capacitors in parallel (as we did on our prototype) although a low-leakage electrolytic may be cheaper.

ZD1 protects the gate of Q2 from excessive voltages, which may be due to power-supply spikes in the system. It clamps the gate to around +16V and –1V, well within its ±20V rating.

The current through ZD1 is limited by the relatively high base impedance of Q1. The maximum base current with a 14.4V supply is (14.4V – 0.5V) ÷ 820kΩ = 17µA. The highest beta for a BC547 is around 800 at 2mA, but it's less than half that at very low currents, so the maximum figure is around 400. That translates into a collector current of no more than 17µA × 400 = 6.8mA.

That's more than enough current to pull the gate of Q2 to 0V, but low enough that neither Q1 nor ZD1 will

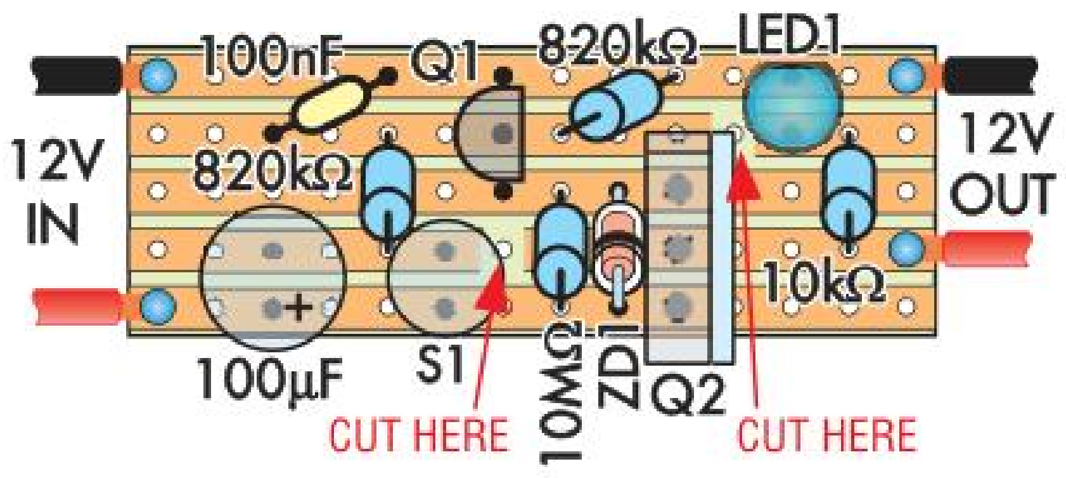


Fig.3: above, a guide to building the *P-channel* version on a piece of stripboard. Note the two locations where the tracks are broken, with a knife or drill. Ensure you avoid the possibility of component leads or exposed metal tabs shorting each other if components are moved slightly.

Note: view of both boards is from the *top* (component) side, just like PCB layouts.

The copper strips are on the *underside* of the board, as if you were looking through the board with x-ray vision.

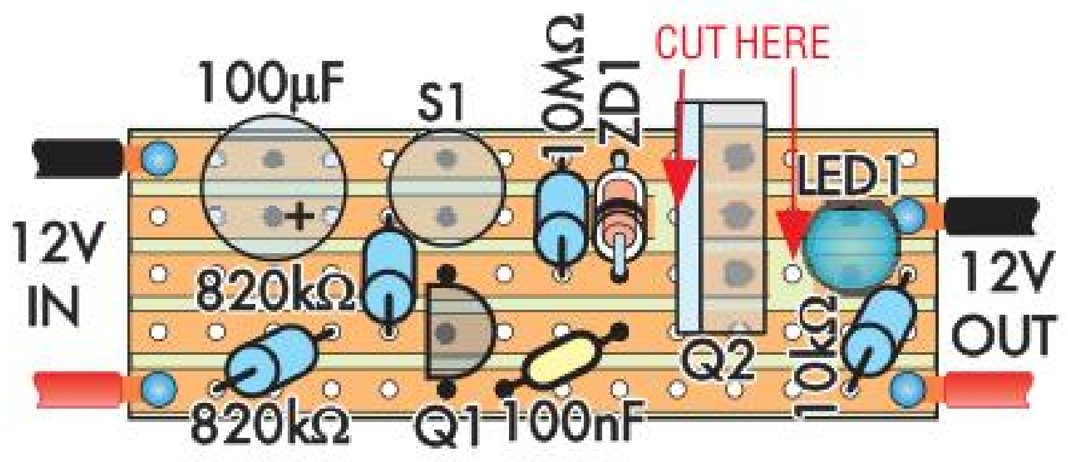


Fig.4: this is the stripboard layout for the *N-channel* version of the circuit. As with the circuit diagram, this is basically just a flipped version of Fig.3 to compensate for the difference in behaviour between an *N-channel* and *P-channel* MOSFET.

be damaged if the supply voltage is high enough for ZD1 to conduct. Even if the supply voltage is considerably higher (which it would need to be, for ZD1 to conduct), nothing is going to burn out.

The 100nF capacitor between the base and emitter of Q1 is important because the supply voltage in a vehicle can vary a great deal, from around 10V when cranking up to around 14.4V when the battery is being charged. And there can also be a great deal of noise and some significant voltage spikes on the supply line. This 100nF capacitor prevents supply spikes from causing Q1 to switch off briefly, which would cut power to the dashcam.

Optional components

Pushbutton switch S2 is shown wired across the vibration switch, as a manual means of forcing the unit to switch on. But you will notice that we have left it out of our PCB designs. That's because merely bumping the PCB is enough to switch the unit on; so it would probably come on even before you could press S2. So while it makes sense in theory, in practice, you don't need it.

LED1 and its 10kΩ current-limiting resistor are wired across the output so you can easily see if the unit's output is switched on. This only adds about 1mA to the current consumption when the unit is on. It's handy for debugging and testing, but you don't need it, so you could leave it off your version.

By the way, the circuit draws almost no power when off – basically just the leakage current of the 100µF capacitor, which is usually around 1µA. So it will not affect your vehicle's battery life.

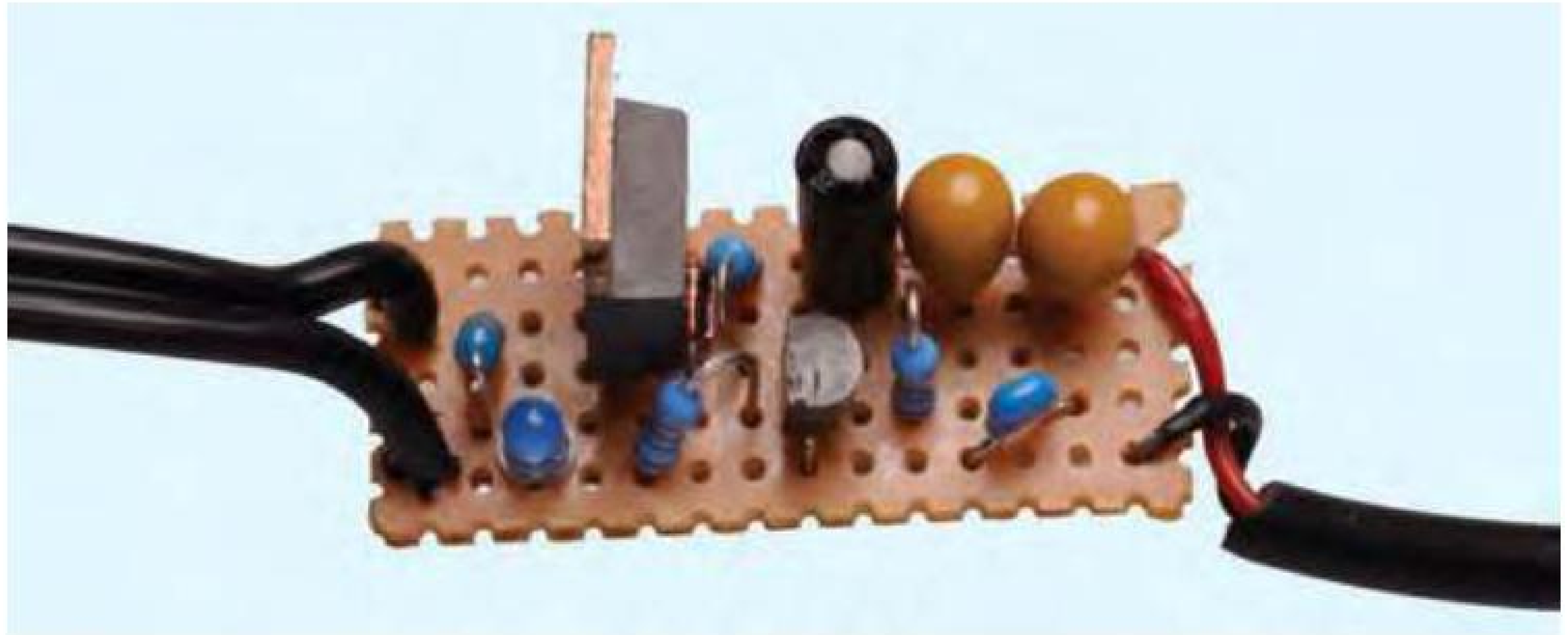
The vehicle itself will typically draw around 10mA, plus another 10mA or so of battery self-discharge, for a total of around 20mA, which is 20,000 times more than this circuit draws.

Alternative versions

Fig.2 shows how you can build the circuit using an N-channel MOSFET instead of a P-channel MOSFET. Essentially, everything is inverted. Q1 changes from an NPN transistor to a PNP transistor. All the other parts are the same, just connected differently. You might want to build this version just because it's easier and cheaper to get a high-current N-channel MOSFET. You may even have one lying around somewhere.

But keep in mind that it interrupts the negative power connection, rather than the positive connection, meaning you can only really use it to switch devices which do not connect to any other powered devices (unless they get their power from the same socket).

As there are so few components in this circuit, I built mine on stripboard ('Veroboard') and you could do the same. The stripboard component layouts are shown in Figs.3 and 4.



This photo is taken from the opposite side of the stripboard than the diagram above (ie, output on left and input on right) to more clearly show the smaller components which could be otherwise hidden.

SMD PCB version

However, many people don't like stripboard (to be honest, I'm normally one of them!), so I also designed a small PCB for the P-channel version ***only***. The PCB, coded 05102191, is 25.4 x 19.5mm and available from the PE PCB Service

This uses SMD parts (see Fig.5) so has the advantage of being much shorter and thinner, at just 25 × 20 × 5mm. It's therefore suitable for encapsulation in a smaller (~16mm diameter) piece of heatshrink tubing, making it easy to tuck away.

The only through-hole part used is the vibration sensor itself, S1. This is laid on its side and held down to the board using a couple of wire straps to keep everything nice and rigid, minimising the overall size of the module.

The only difference in the circuit is that we've used two parallel 47µF 16V SMD ceramic capacitors rather than a single 100µF electrolytic, as 100µF 16V SMD capacitors tend to be larger and more expensive. In addition to being compact, ceramic capacitors are very reliable and more heat-tolerant compared to electrolytics.

We won't go into any great details regarding the assembly of the SMD version, although we have an alternative SMD parts list at right.

Construction

One critical aspect of construction is to note that one of the leads of the vibration sensor may be extremely thin and easy to break.

It depends on exactly which sensor you use; we used a very common type (SW-18010P) and managed to break one lead while testing it. Interestingly, the other lead is really thick and presumably intended to allow it to be rigidly mounted to the board.

The layout for the P-channel version is shown in Fig.3, with the layout for the N-channel version in Fig.4. As with the circuits, they are almost a mirror-image of each other.

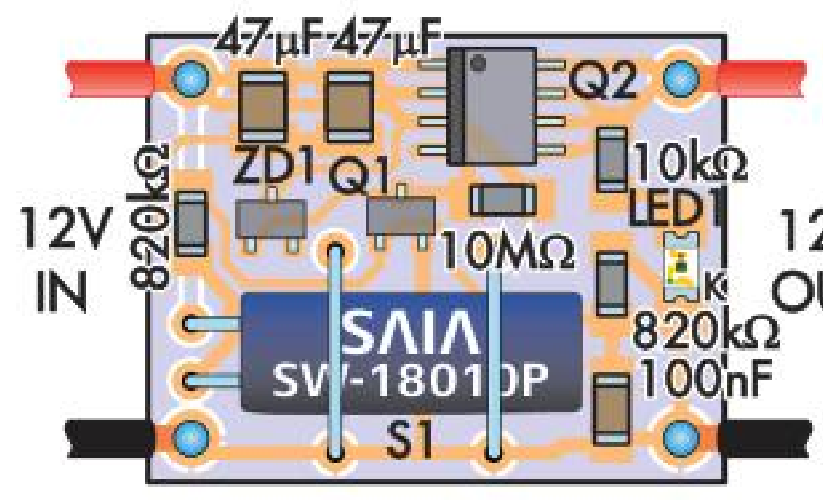


Fig.5: the PCB overlay for the SMD version of Fig.1 – the *P-channel* version of the circuit. It is slightly taller but it is narrower and much thinner, so it should give a more compact result. MOSFET Q2 is in an 8-pin SOIC package which is easy to solder, as are all the other components. Note the two 47µF capacitors connected in parallel, which are used instead of a single 100µF capacitor which would be larger.

Both designs require tracks to be cut in two places; the cuts are shown on either side of Q2. Look closely at Fig.3 and Fig.4; the breaks are shown but they are visually subtle. You can make these cuts with a sharp knife but make sure you remove a fair bit of copper so they can't accidentally come in contact.

Some people prefer to use a ~4mm drill turned by hand but it needs to be sharp or it will not cut the copper. It probably wouldn't hurt if you actually drilled through the board but might weaken it slightly.

Having made the two track cuts, fit the components. The axial components (resistors and zener diodes) are all mounted with their leads 0.2-inch or 5.08mm apart, so they will need to have their leads bent so that they sit on the board in a semi-vertical position.

You have a choice of which side to place the component body; try to orient them to avoid the possibility of component leads shorting together.

Make sure that the cathode stripe of ZD1 faces in the correct direction, as shown in Fig.3 and Fig.4.

The radial components (electrolytic capacitor, sensor, LED) have their leads soldered to adjacent tracks, 0.1-inch or 2.54mm apart, and this should be the natural pin spacing of these parts, making it easy.

Watch the orientation of the electrolytic capacitor; its positive lead is longer and should be located where shown with the + symbol in Fig.3 or Fig.4.

Similarly, you will probably not need to bend the leads of Q1 or Q2 as they will likely already have the requisite 0.1-inch spacing. Watch the orientation of both parts.

The orientation of the vibration sensor doesn't matter since it just acts as a switch.

Wiring it up

With all the components on the board, now you just need to wire up the plug and socket.

At this stage you can simply purchase a vehicle accessory (cigarette lighter) plug and socket separately, or use something like Jaycar's 'cigarette lighter double adaptor' (Cat PP2006).

I did the latter opened up the plug (undoing one screw and unscrewing the tip), removed the contacts, de-soldered the wires and pulled them through the strain-relief boot. That gave me two pre-wired sockets plus a plug, which I put aside since I already had a pre-wired accessory plug (eg, Jaycar Cat PP1995).

The PP1995 plug wires went straight into the stripboard holes and I soldered them to the tracks, although I found I had to add some flux paste as I had difficulty getting the wires to take solder. I had to drill the board holes for the socket wires out to 1.5mm. After pushing the wires through the holes, I bent them over to come in contact with the copper strips and soldered them in place.

Testing

Ideally, testing should be done with a current-limited 12V DC supply in case there is a short circuit on the board, or one component has been installed incorrectly.

This can easily be achieved by connecting a 100Ω 5W or 220Ω 1W resistor in series with the supply. You can monitor the voltage across this resistor to get an idea of the circuit's current draw.

You can connect the supply to the cigarette lighter plug using a couple of alligator clip leads.

LED1 should light up immediately and you should get a reading of around 0.1-0.2V across the resistor due to the 1mA used to light it. Leave the board alone for about five minutes, being careful not to touch or bump it, and LED1 should go out and the voltage across the safety resistor should drop to no more than a few millivolts. When LED1 goes out, give the board a tap. The LED should switch back on. If it does, everything looks good.

If LED1 doesn't go out, or it doesn't go back one when you tap the board, check it carefully for short circuits. It's

Parts list – 12V movement/vibration switch

P-channel version on strip board

1 piece of stripboard/Veroboard, five strips x 14 holes
1 Soyo SW-18010P vibration sensor, ***or similar*** (S1)
1 car accessory power extension cable, length to suit
(cut in half to get cables with plug and socket on ends)
Short lengths of various diameter heatshrink tubing

Semiconductors
1 BC547 NPN transistor (Q1)
1 IRF4905 P-channel MOSFET or equivalent (Q2)
1 blue 3mm LED (LED1)
1 15V 0.4W or 1W zener diode (ZD1)

Capacitors
1 100µF 16V/25V low-leakage electrolytic ***or***
2 47µF 16V tantalum
1 100nF ceramic

Resistors (all 0.25W, 1% or 5%)
1 10MΩ *(brown black green brown or brown black black yellow brown)*
2 820kΩ *(grey red yellow brown or grey red black range brown)*
1 10kΩ *(brown black orange brown or brown black black red brown)*

Parts substitutions for N-channel version

1 BC557 PNP transistor (Q1)
1 IRF540N N-channel MOSFET or equivalent (Q2)

Parts for SMD version on PCB

1 double-sided PCB, coded 05102191, 25.4 x 19.5mm
available from the *PE PCB Service*
1 Soyo SW-18010P vibration sensor, or similar (S1)
1 car accessory power extension cable

Semiconductors
1 AO4421 P-channel MOSFET or equivalent, SOIC-8 (Q1)
1 BC847 NPN transistor, SOT-32 (Q2)
1 blue 3216/1206 LED (LED1)
1 15V 0.25W zener diode, SOT-23 (ZD1)

Capacitors
2 47µF 16V X5R ceramic, SMD 3226/1210 package
1 100nF 50V X7R ceramic, SMD 3216/1206 package

Resistors (all SMD 3216/1206 package, 1%)
1 10MΩ 2 820kΩ 1 10kΩ

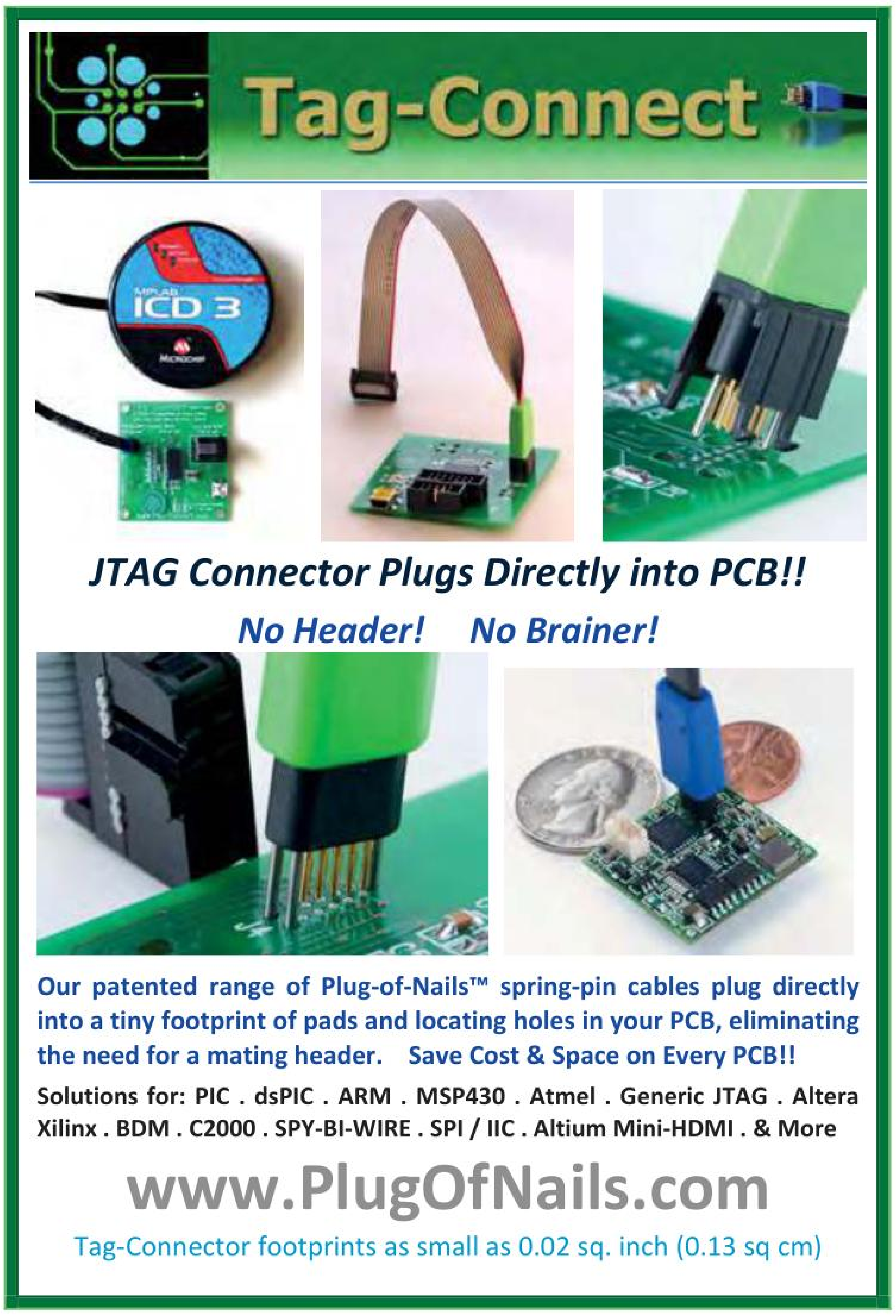
Where to get the vibration sensor:

Pakronics (**www.pakronics.com.au**) have two vibration sensors in stock: the recommended Soyo SW-1801 P (Cat ADA1766), described as 'easy to trigger', plus a 'hard to trigger' (ie, less sensitive) Cat ADA 1767.

Alternatively, element14 (**au.element14.com**) has a range of slightly different 'Comus' vibration switches (Cat 607253 and 540626) which could also be used in this project.'.

(These sensors are the ones in the photo at the bottom of the article's second page – the Soyo SW-18010P on the left and the Comus [element14] on the right.)

Cheap sensors are currently avaible from **Amazon.co.uk** – search for: 'sourcing map SW-18010 High Sensitivity Spring Electronic Vibration Sensor Switch 30Pcs'. At the time of writing, just go to: **http://bit.ly/pe-feb20-sense** where there is a good choice. Note that the SW-18015P and SW-18020P versions are probably too insensitive to be useful



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Unfortunately we didn't have any clear heatshrink large enough – so red had to do! If there is any danger of any component being shorted (remember there's lots of movement under a dashboard) we'd also be inclined to crimp the edges of the heatshrink together before shrinking it.

easy to accidentally short adjacent tracks on stripboard. It could also be due to a leaky electrolytic capacitor.

Use a DMM set to measure ohms and probe adjacent tracks. If you get a reading lower than 10Ω, chances are you have a short circuit.

Also check your component placement and orientation, using Fig.3 or Fig.4 as a reference.

If it's working, remove the safety resistor and power the circuit directly from 12V. Measure the voltage at the socket. You should get a reading of +12V with the red probe touching the small contact area inside the base of the socket and the black probe on the inner metal surround.

You can then try plugging a vehicle accessory such as a dashcam or GPS into the socket and check that it powers up correctly.

Finishing it off

Assuming all is well, disconnect everything and add some heatshrink insulation. It's a good idea to slip some tubing over the TO-220 package and shrink it down to ensure it can't short against any adjacent components. Do the same with any other components you think could short if they move or are bent.

Then slide larger diameter clear heatshrink tubing over the cigarette lighter plug and onto the board and shrink it down, so it can't short against any exposed metal that may be in the vehicle, or loose items like keys.

Installing it in the vehicle is simple. Just plug it into the accessory socket, plug in your dashcam, GPS or whatever, then find somewhere to tuck the circuit board away. It would be a good idea (at least initially) to put it somewhere where you can observe LED1, ideally from outside the vehicle, through a window.

Leave it for 5-10 minutes, somewhere where the vehicle is not going to be rocked by vehicles passing at high speeds (eg, trucks).

Then check to see if LED1 has gone out. If it has, open the door and get in. The motion from doing so will probably trigger the unit and switch LED1 back on. Otherwise, give the board a little nudge and check that it switches back on.

You may find the unit is too sensitive; perhaps passing traffic often triggers it. In this case, you have two main options. The easiest is to add some cushioning around it like foam, to reduce the amount of movement and vibration transferred to it, reducing its sensitivity. You will need to experiment with the type and thickness of material to achieve a good result.

If that's no good, you will have to remove the vibration sensor and fit a less sensitive version. We've found that they are usually too sensitive, so you're better off with the foam.

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USB Keyboard and Mouse Adaptor for Micros

by Tim Blythman

How can you connect a keyboard, or a mouse, to a microcontroller, especially now that most keyboards and mouses have a USB plug? This *Adaptor* is the answer. It makes it simple to connect a USB keyboard or mouse to any micro! It's small, easy to build and it won't break the bank!

A keyboard or mouse would be a great addition to your Micromite or Arduino project, especially given how cheap a USB keyboard or mouse is these days. But there hasn't been an easy way to do it – until now!

One of the most challenging parts of designing a project around a microcontroller is providing a way for the user to control it.

Touchscreens are great, but let's face it: an on-screen keyboard is not particularly easy to use, and usually takes up most of the screen.

A touchscreen *plus* a physical keyboard is a superior user-interface solution. And if you can add a mouse cursor, so much the better!

Plus, there's the added bonus that many USB keyboards and mouses are wireless these days. How convenient is that, an input method for your microcontroller project that doesn't even need to be tethered to it via a cable?

And this is a far easier way to achieve that than a home-brew wireless communication system. It's just 'plug and play'.

We're using the term 'mouses' as the plural for a computer mouse, as opposed to 'mice', which usually refers to the mammalian kind, or even 'meeces' as you'd find in a comic!

The compact unit presented here bridges the gap between a USB keyboard or mouse and a simple microcontroller. The keyboard or mouse plugs into one side (or its tiny dongle, if it's wireless) and a serial data stream is produced from the other side that any micro would find dead easy to read.

There are various settings to adapt the serial data stream to your particular requirements, including a mode which allows detection of practically all keys on a keyboard with just a single byte transmitted for each keypress.

Similarly, for a mouse, there are multiple modes to choose from, including one which supports three movement axes and up to five buttons.

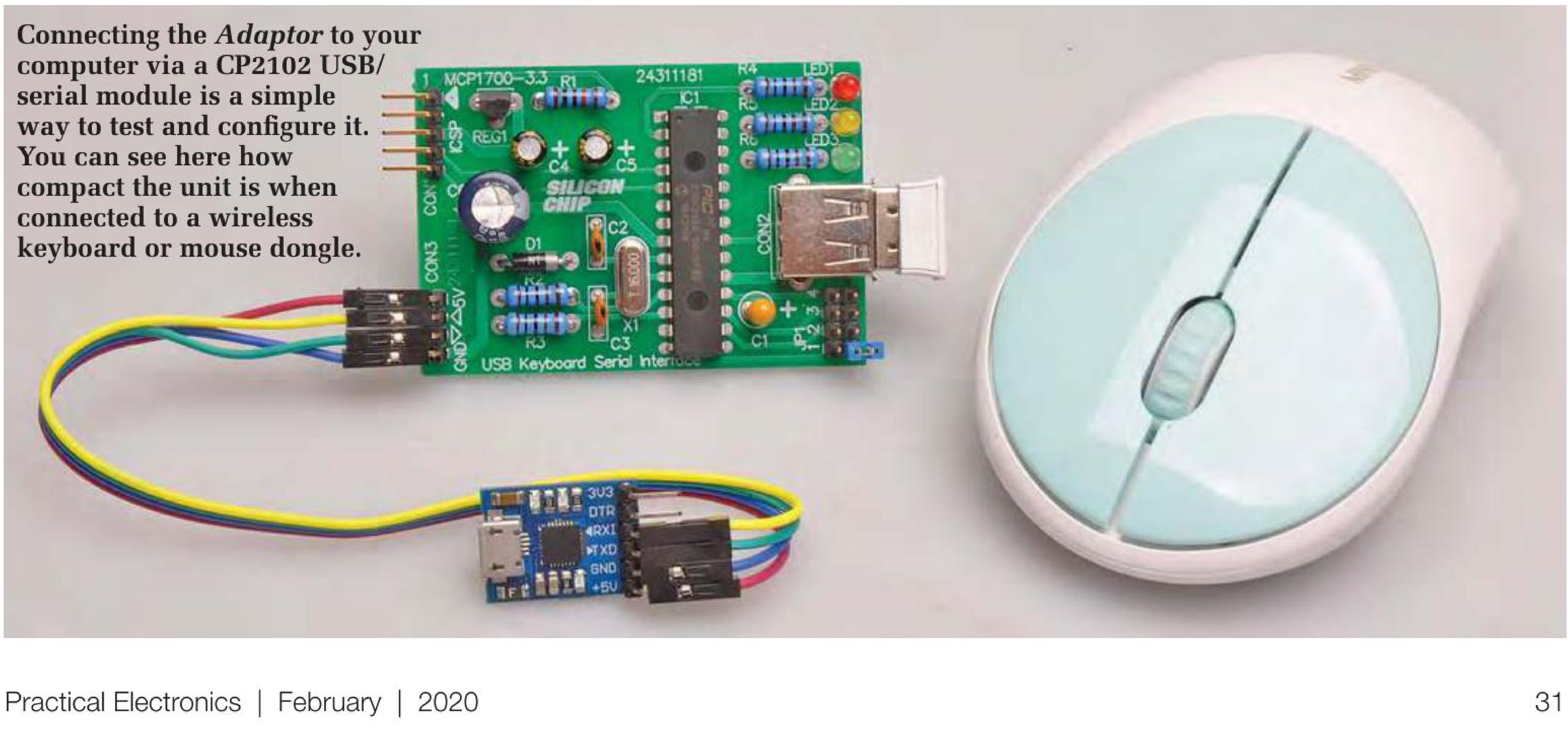
With USB hardware being cheap and plentiful, it's now possible to easily and cheaply add these peripherals to your latest project.

By the way, we know that you can also do this with a USB host shield or an Arduino Due. But our solution has two big advantages: first, it is cheaper and second, it's definitely easier for you, and smaller too.

How it works

The *Adaptor* has a USB Type-A socket at one end, for plugging in a keyboard or mouse, and a four-way pin header at the other end which has a standard TTL serial port interface and is also used to supply 5V DC power to the board (and keyboard/mouse).

Any device that can supply 5V and communicate via serial can therefore



Connecting the *Adaptor* to your computer via a CP2102 USB/serial module is a simple way to test and configure it. You can see here how compact the unit is when connected to a wireless keyboard or mouse dongle.

make use of a USB keyboard or mouse – wired or wireless!

Features and specifications

- **Simple and low cost**
- **Accepts either a USB keyboard or mouse (two different firmware images)**
- **Translates key presses or mouse movement/clicks into serial data**
- **Just one pin on a micro required to receive either keyboard or mouse data**
- **Build two to connect both a keyboard and a mouse up to the same micro**
- **Configurable baud rate from 1200 to 115,200**
- **ASCII translation for keyboards with optional codes for special keys**
- **VT100 emulation option for keyboards**
- **Supports mouses with up to three axes and five buttons**
- **Configurable mouse update rate and scaling factor**
- **Onboard status LEDs**
- **Powered from 5V DC**

When a keyboard is connected, the keystrokes are converted into data that is sent down the serial transmit line to whatever device is attached.

Similarly, when a mouse is plugged in, data is generated on the serial port when you move it or click the buttons. This data is designed to be easy for a microcontroller to interpret and act upon.

The *USB Keyboard and Mouse Adaptor* also has three LEDs to indicate its status. The red LED lights up when 5V power is applied.

When a compatible keyboard or mouse is connected, the red LED extinguishes and the green LED illuminates instead. The yellow LED flashes each time keyboard or mouse activity is detected, and it lights up continuously while the unit is being configured.

There are also four jumpers on the board. JP1 can be used to enter setup mode (you can also do this via the serial console). JP2 temporarily resets the configuration to default, while JP3 permanently resets it to default upon power-up (ie, writes default settings to Flash). When JP4 is inserted, configuration mode is not available, so the configuration can't be accidentally changed.

Circuit description

The circuit, shown in Fig.1, is based on a PIC32MX270 microcontroller (IC1) which is closely related to the chip used for the 28-pin Micromite we have used in so many projects.

The only difference between the PIC32MX270 used here and the PIC32MX170 used for the Micromite is that the -270 version has USB support, with pins 21 and 22 able to be used either as general-purpose I/Os (GPIOs) as RB10/RB11 or for USB communication (D+/D–).

These are wired directly to the USB Type-A socket (CON2) which is also fed the board's 5V power supply, to power the keyboard or mouse.

The USB version of this chip has two fewer I/O pins than the non-USB version, which are instead used to supply power to the internal USB controller (USB3V3) and for USB bus voltage sensing (V_{BUS}).

IC1's clock source is 16MHz crystal X1, connected between its clock input and output pins (pins 9 and 10), along with 22pF load capacitors. This is required to ensure that the USB communication timings meet the specifications. IC1's internal PLL (phase-locked loop) multiplies this 16MHz source up to 48MHz for its instruction clock and that is then divided by four to get the required 12MHz USB clock.

Indicator LEDs LED1-LED3 are driven by GPIO pins RA0, RB15 and RB13 respectively (pins 2, 26 and 24), via 1kΩ current-limiting resistors.

Jumper headers JP1-JP4 connect between GPIO pins RB9, 8, 7 and 5 (pins 18-16 and 14) and ground. Internal pull-ups on those pins keep them high when the headers are not shorted, allowing IC1 to detect the presence or absence of the four jumpers.

Power supply

IC1 requires a low-ESR capacitor between pin 20 (V_{CAP}) and ground, of at least 10µF, to filter its internal 1.8V core supply. To meet the low-ESR requirement, we are specifying a 47µF tantalum capacitor, only because we have previously found that lower-value tantalum capacitors do not always meet the ESR requirement of less than 1Ω.

That is why we have often used SMD ceramics in this role in the past, as they can be relied upon to have a low ESR, even at 10µF. We have also found ceramics to be more reliable in the long-term.

However, in this case, we've decided to stick with a through-hole component, hence the use of a tantalum capacitor.

Power is fed into the board via the 5V and GND connections of CON3, which also carries the serial data.

The supply has to be very close to 5V: ±5% is required by the USB specification, ie, 4.75-5.25V. This supply is used to power the USB keyboard or mouse directly.

Fortunately, most keyboards and mouses have modest power requirements, so as long as your supply can provide a couple of hundred milliamps, that should be plenty.

The 5V supply is bypassed by a 10µF capacitor, then fed via schottky diode D1 to another 10µF capacitor and regulated to 3.3V by REG1, an MCP1700 low-dropout (LDO) regulator. This has a 10µF output filter capacitor.

We've tested several such capacitors to ensure that they have an ESR of less than 2Ω, as specified in the MCP1700 data sheet.

The 3.3V output of REG1 powers IC1 and is fed to its three supply pins: VDD (pin 13), analog VDD (AVDD, pin 28) and USB3V3 (pin 23), which powers the internal USB transceiver.

Diode D1 ensures that any high current pulses drawn from the 5V rail do not come from REG1's input filter capacitor and assists with the stability of the 3.3V rail when transients occur on the 5V rail.

The 10kΩ pull-up resistor connected between pin 1 ($\overline{MCLR}$), and the 3.3V rail prevents spurious resets of the micro which may occur due to EMI or power-supply transients. $\overline{MCLR}$ is connected to CON1, the in-circuit serial programming (ICSP) header, along with the 3.3V supply for IC1 and its PGED1 and PGEC1 programming pins. The pinout of IC1 suits a PICkit 3 or 4.

Microcontroller IC1 has two internal hardware UARTs (serial ports). These can be mapped to various combinations of pins. In this case, we have set up U1TX on pin 11 (RPB4) and U1RX on pin 12 (RPA4). These go to CON3, the serial/power header, via 1kΩ series resistors. These allow the serial port to work safely with either 5V or 3.3V devices, as well as providing some extra ESD (static electricity) protection.

Operating modes

There are several different settings which can be changed to suit your requirements, but the most important one for keyboards is the translation mode. It can be set to translate either to 7-bit ASCII, 8-bit ASCII or VT100.

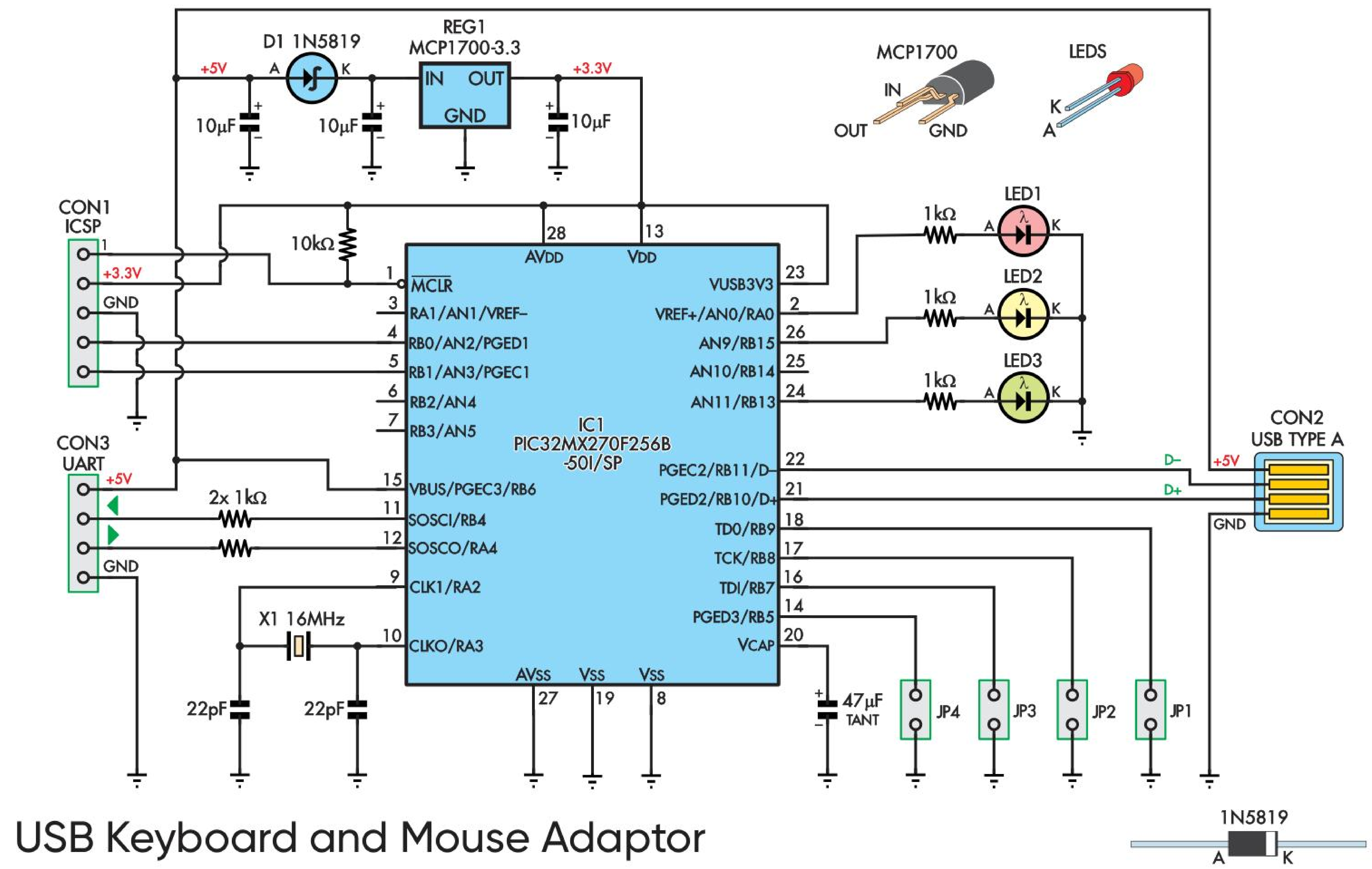

D1 1N5819
REG1
MCP1700-3.3
+5V
A
K
IN
OUT
GND
+3.3V
10μF
10μF
10μF
MCP1700
IN
OUT
GND
LEDS
K
A
CON1
ICSP
1
+3.3V
GND
10kΩ
28
AVDD
13
VDD
1
MCLR
3
RA1/AN1/VREF–
4
RB0/AN2/PGED1
5
RB1/AN3/PGEC1
6
RB2/AN4
7
RB3/AN5
IC1
PIC32MX270F256B
-50I/SP
23
VUSB3V3
2
VREF+/AN0/RA0
26
AN9/RB15
25
AN10/RB14
24
AN11/RB13
1kΩ
LED1
1kΩ
LED2
1kΩ
LED3
CON3
UART
+5V
GND
2x 1kΩ
15
VBUS/PGEC3/RB6
11
SOSCI/RB4
12
SOSCO/RA4
9
CLK1/RA2
10
CLKO/RA3
X1 16MHz
22pF
22pF
22
PGEC2/RB11/D–
21
PGED2/RB10/D+
18
TDO/RB9
17
TCK/RB8
16
TDI/RB7
14
PGED3/RB5
20
VCAP
AVSS
27
VSS
19
VSS
8
47μF
TANT
JP4
JP3
JP2
JP1
CON2
USB TYPE A
D–
D+
+5V
GND
USB Keyboard and Mouse Adaptor
1N5819
A
K

Fig.1: the circuit for the *USB Keyboard and Mouse Adaptor* is based around PIC32 microcontroller IC1. It communicates directly with the USB keyboard or mouse plugged into CON2, which is powered from the external 5V supply. The micro translates keystrokes or mouse movements received and sends them to the serial port on pins 2 and 3 of pin header CON3.

In 7-bit ASCII mode, key presses will produce standard characters such as lower case or upper case letters, numbers, punctuation, space, Enter, tab, backspace and so on. Other key presses, such as arrow keys, page up/down, print screen and so on are simply ignored.

If you have a number pad, numeric codes are produced in this mode, but only when Num Lock is active.

Ctrl-letter key combinations also work in 7-bit ASCII mode. For example, Ctrl-C maps to ASCII code 3, which is used by the Micromite and many other systems to stop the currently running program. Control plus the letters A-Z map to ASCII codes 1-26.

In 8-bit ASCII mode, all the same 7-bit ASCII characters are still sent but extended characters are also produced from other keypresses. This mode is useful if you need to be able to process presses of the arrow keys, home/end, delete, F-keys, modifier keypresses (eg, Shift, Ctrl, Alt), non-numeric number pad keys and so on.

Rather than invent a new scheme, we've implemented the standard Arduino 'Keyboard Modifiers' scheme, which you can view on the following web page: **http://bit.ly/pe-feb20-mod**

However, that scheme is far from complete. For example, it does not provide any way of knowing when a modifier key such as Shift, Ctrl or Alt is released.

So there's no way to know for sure whether a key was pressed while one of these modifier keys were held down. And some keys on the keyboard, such as print screen and pause/break, are missing from the Arduino modifiers list.

So we've added to that list – see Table 1. Since the Arduino keyboard modifiers are a subset of ours, they are compatible; your software can merely ignore any codes it doesn't understand. But the new scheme gives you a much better idea of what keys the user is actually pressing. Note that all the added key up events have the same code as the key down events, plus 16 (hexadecimal 10).

VT100 emulation mode goes a step further and translates certain keypresses into commands or 'escape sequences' which are compatible with the old-fashioned (1978!) VT100 video terminal. Those commands are still in use today in Unix-based operating systems. They allow for things like moving the cursor around the screen, erasing characters and so on.

The *Adaptor* doesn't produce all of VT100 escape sequences – just those which can be generated from a keyboard.

Another mode setting determines what happens when you press Enter on the keyboard.

The unit can either generate a single code: either carriage return (CR, ASCII 13) or line feed (LF, ASCII 10). Or it can generate two codes: CR, then LF. A carriage return typically moves the cursor to the left-hand side of the screen while line feed moves it down one line (and possibly scrolls the display if it's already at the bottom).

If you're programming the receiving micro yourself, a single CR (the default) or LF code would probably be easier to handle.

But you may need to set the unit to produce the CR/LF pair when using it with pre-existing software that expects that combination, such as a 'dumb terminal', where this code pair moves the cursor to the start of the next line.

Mouse modes

There are three options for the serial data format produced when using the Adaptor with a mouse. In all modes, mouse movements are relative, so the receiving device must accumulate the movements to track the mouse cursor position.

The default mode is the Microsoft Serial Mouse format. This consists of three bytes of 7-bit data for each update, containing the current mouse button states and the horizontal and vertical movement in pixels since the last update.

In this mode, we set the eighth bit of each byte to 1. The data can therefore be decoded as either 8-bit data with one stop bit or 7-bit data with two stop bits, but it is also compatible with systems that expect 7-bit data with one stop bit, as the extra bit simply appears as extra idle time between bytes.

The Microsoft Serial Mouse format only supports two buttons and eight bits of movement resolution in each axis, so we developed an eight-bit version that supports three buttons and nine bits of movement resolution. That is the second mouse mode that you can select.

The third mode produces human-readable CSV data, with four fields. The first field is a bitmap of the button states and it supports up to five buttons. The next three fields are three-axis delta values, corresponding to the x, y and z axes. Although not many mouses support a third (z) axis, this data is sent over USB, so we have included it in this mode.

Note that most of the mouses that we tried which had mouse wheels did not report mouse wheel rotation using the basic HID protocol, so it's unlikely that you will be able to detect rotation of the mouse wheel using this *Adaptor*.

The software

The software running on microcontroller IC1 is programmed to communicate using the USB 'Human Input Device' or HID protocol, the standard used by keyboards and mouses (and also some other devices).

This requires the USB interface to run in 'host mode', which is different from the 'device mode' that you would use for communicating with a computer via its USB port.

The HID driver is from Microchip, which comes with several other different USB drivers in their 'Harmony' library. This is integrated with their MPLAB X IDE (Integrated Development Environment).

The Harmony utility automatically generates the code for low-level USB interfacing, such as detecting and enumerating connected USB devices. We had to add code to activate the USB interface, query it and respond to events that occur.

So that allows us to get keystroke data from keyboards and mouse movement/click data from mouses. But there are further difficulties in converting the keystroke codes from a USB keyboard into a useful form of serial data.

For the keyboard version of the firmware, the Microchip USB library calls our user function every time a keyboard event occurs. Mostly, these are to report that a key has been pressed or released, but there are also events indicating when a compatible keyboard is attached or detached. We use these events to change the status of the red and green LEDs.

Each report from the keyboard contains a list of which keys are currently depressed (up to six) and which combining keys are pressed (shift, Ctrl, Alt). The report needs to be filtered so that keys that are still down in subsequent reports are not detected as pressed again. These events are then decoded.

The keystroke events from the keyboard do not neatly map to the ASCII codes, so we need to perform some table lookups based on the mode and shift keys to determine what ASCII code to produce. The basic 7-bit ASCII codes such as letters, numbers and punctuation are handled first.

If the software can't find a match to a 7-bit ASCII code for a keystroke, then it checks whether Enter has been pressed, and if so, it generates either CR, LF or CR/LF, depending on the mode setting as explained above.

If the keystroke didn't correspond to a 7-bit ASCII code or Enter, and if 8-bit extended ASCII mode or VT100 mode are enabled, it then checks to see whether the keystroke should produce one or more codes to suit those schemes.

Finally, Num Lock, Caps Lock and Scroll Lock key presses are detected and internal flags set so that their states can be taken into account when decoding subsequent keys. A message is also sent back to the keyboard to update the respective status LEDs.

The mouse version of the firmware is somewhat simpler but works similarly. A function is called each time the mouse is moved or a button is clicked (or released) and it then formats and sends the corresponding serial data to the microcontroller.

Every time data is sent to the serial port, the yellow LED is switched on and a timer is started. The yellow LED is switched off after it has been on for 50ms, thus giving the effect of flashing briefly for each keystroke or mouse movement/clips.

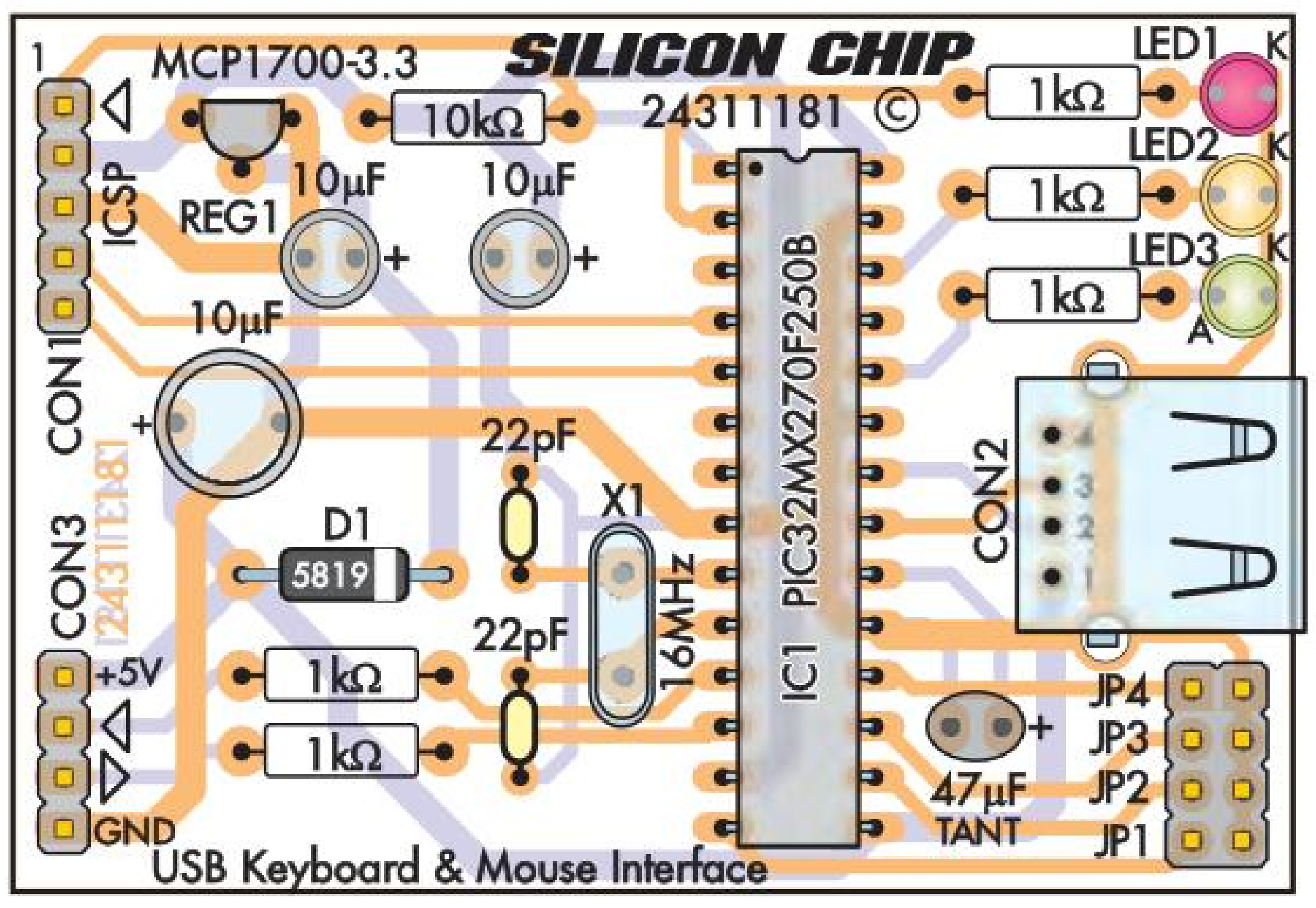
Construction

The *USB Keyboard and Mouse Adaptor* is built on a compact PCB measuring 64mm x 44mm, which is coded 24311181 and is available from the *PE*

Table 1: 8-bit keyboard modifier codes

Key	Hex code
KEY_LEFT_CTRL	0x80
KEY_LEFT_SHIFT	0x81
KEY_LEFT_ALT	0x82
KEY_LEFT_GUI	0x83
KEY_RIGHT_CTRL	0x84
KEY_RIGHT_SHIFT	0x85
KEY_RIGHT_ALT	0x86
KEY_RIGHT_GUI	0x87
KEY_LEFT_CTRL_UP	0x90 *
KEY_LEFT_SHIFT_UP	0x91 *
KEY_LEFT_ALT_UP	0x92 *
KEY_LEFT_GUI_UP	0x93 *
KEY_RIGHT_CTRL_UP	0x94 *
KEY_RIGHT_SHIFT_UP	0x95 *
KEY_RIGHT_ALT_UP	0x96 *
KEY_RIGHT_GUI_UP	0x97 *
KEY_RETURN	0xB0
KEY_ESC	0xB1
KEY_BACKSPACE	0xB2
KEY_TAB	0xB3
KEY_F1	0xC2
KEY_F2	0xC3
KEY_F3	0xC4
KEY_F4	0xC5
KEY_F5	0xC6
KEY_F6	0xC7
KEY_F7	0xC8
KEY_F8	0xC9
KEY_F9	0xCA
KEY_F10	0xCB
KEY_F11	0xCC
KEY_F12	0xCD
KEY_INSERT	0xD1
KEY_HOME	0xD2
KEY_PAGE_UP	0xD3
KEY_DELETE	0xD4
KEY_END	0xD5
KEY_PAGE_DOWN	0xD6
KEY_RIGHT_ARROW	0xD7
KEY_LEFT_ARROW	0xD8
KEY_DOWN_ARROW	0xD9
KEY_UP_ARROW	0xDA
KEY_CAPS_LOCK_ON	0xE0 *
KEY_CAPS_LOCK_OFF	0xE1 *
KEY_SCROLL_LOCK_ON	0xE2 *
KEY_SCROLL_LOCK_OFF	0xE3 *
KEY_NUM_LOCK_ON	0xE4 *
KEY_NUM_LOCK_OFF	0xE5 *
KEY_PRINTSCREEN	0xE6 *
KEY_PAUSE_BREAK	0xE7 *

*** added by us**



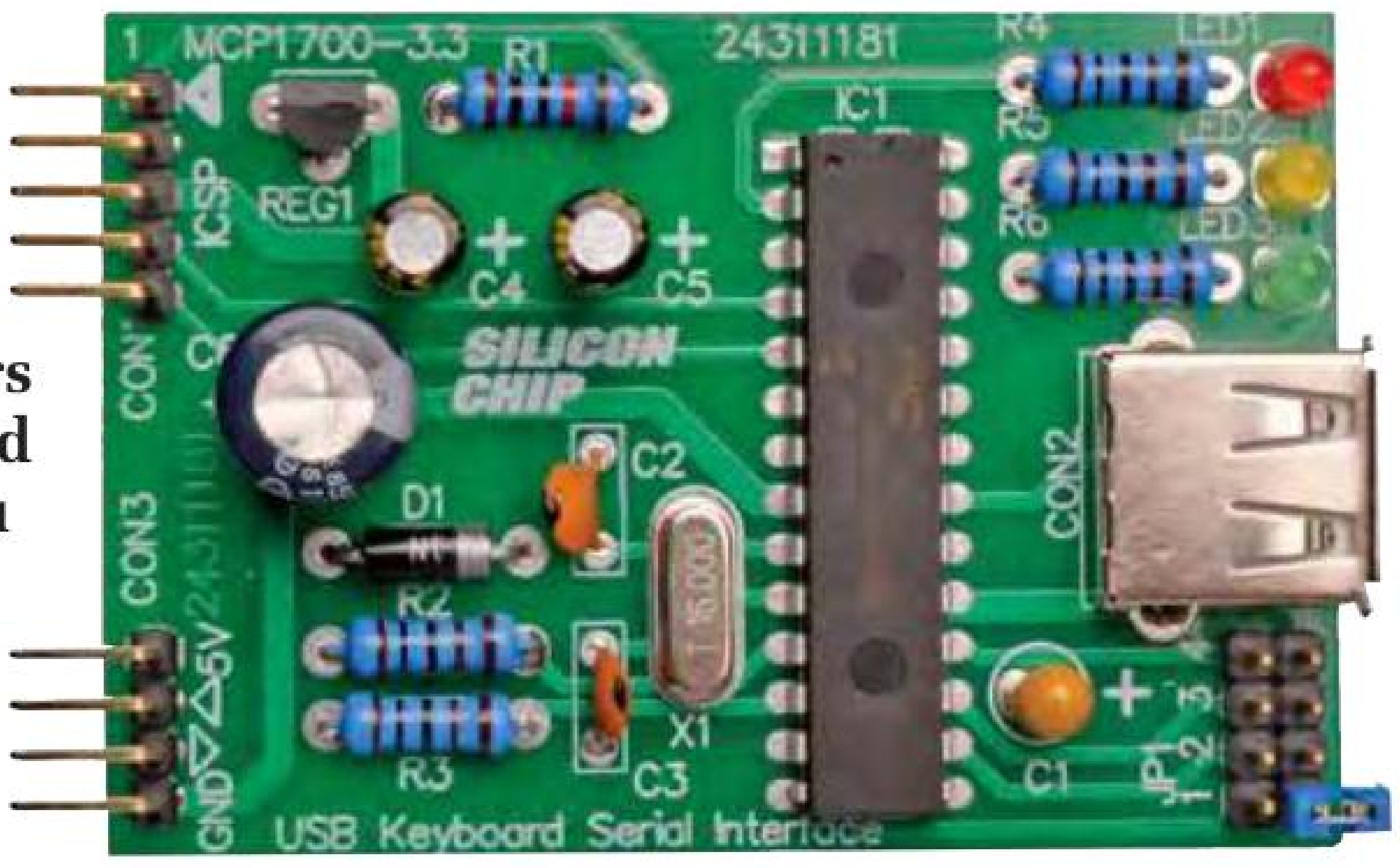


Fig.2: use this PCB overlay diagram and photo as a guide when building the *Keyboard and Mouse Adaptor*. IC1, D1, LEDs1-3 and the tantalum and aluminium electrolytic capacitors are all polarised, so must be fitted with the orientations shown. You can use a vertical or horizontal pin header for CON1 and CON3 to suit your application; note that CON1 is only required to program IC1 in-circuit.

PCB Service. Use the PCB overlay diagram, Fig.2, as a construction guide.

The following instructions assume you have the board oriented with the USB socket on the right and the single-row header pins on the left, as shown in Fig.2.

There aren't many options that need to be considered when building this board. If you have a pre-programmed microcontroller, you can omit CON1, the ICSP programming header. It can always be installed later if necessary.

Start by fitting the resistors where shown. One is a 10kΩ type, so don't get it mixed up with the others. If you have any doubt about the markings (they look similar), check the resistances with a multimeter.

D1 is the only diode, and it must be installed with its cathode band facing to the right. If you have a low-profile HC49US crystal for X1, install it next, as it will probably sit lower than its accompanying capacitors.

Next on the list is the microcontroller, IC1. You can either solder it directly to the board or solder a socket and plug it in. The socket makes it easier to swap the chip but sockets can fail over time due to oxidisation, so it's up to you whether to use one.

Regardless, make sure you solder the part in with the correct orientation, ie, the pin 1 dot/notch towards the top of the board.

The tantalum capacitor is next. It is polarised and will have a '+' marked on its body to indicate the positive lead, which should also be longer than the other. Make sure this lead goes into the pad marked with a '+' sign on the PCB. The ceramic capacitors can be fitted next. They are not polarised and can be installed either way.

Follow with the three regular electrolytic capacitors. Their longer lead is positive and the stripe on the can indicates the negative lead. The positive lead must be soldered to the pad marked with a '+' sign on the PCB. Note that one of the electrolytic capacitors is oriented differently than the others (the one with the more widely spaced pads).

Fit REG1 next. Its legs will need to be cranked outwards and then down to match the PCB footprint. Take care to mount it with the orientation shown in Fig.2.

The LEDs can now be installed. You can push them all the way down onto the board as we did, or bend their leads so that they face to the side, depending on how you are planning to use the board. Regardless, make sure that the anode (longer) lead goes to the pad on the left, away from the nearest edge of the board.

The various connectors and jumper headers can be mounted next. CON2 will only fit one way, with the socket opening projecting out over the edge of the PCB. Ensure it is flush before soldering its pins.

As mentioned earlier, CON1 is only needed if your PIC is not yet programmed. You can use a vertical or right-angle header for both CON1 and CON3. If your crystal is a full-height type, now would be a good time to solder it in place.

If you fitted a socket for IC1 earlier, straighten the IC pins before plugging it into the socket, ensuring that none of the legs fold up under it and that its pin 1 dot/notch lines up with the notch on the socket, as shown in Fig.2.

Programming IC1

If you have a pre-programmed PIC, you don't need to worry about programming it, and you can now proceed to the next section for testing.

Note that if you're using a PICkit 4 to program the chip (which is a bit wider than a PICkit 3), when you plug it into CON1, it may touch the pins of CON3. You should still be able to get a good enough connection to program IC1 despite this.

One potential solution would be to install a vertical header for CON1 and a horizontal header for CON3, or leave CON3 off the board until you've programmed IC1.

Microchip's free MPLAB X IDE or IPE software can be used with a PICkit 3 or PICkit 4 to load the firmware into the microcontroller. Alternatively, you could build the *Microbridge Programmer*, described in our May 2018 issue.

If you don't have a USB/Serial converter (or something similar) to use for testing, then you can use a *Microbridge*, as this can act as a USB/Serial converter as well as a PIC32 programmer.

Connect your programmer of choice to CON1, ensuring that the arrowed pin (pin 1) on the programmer aligns with the arrowed pin on the PCB. If using the MPLAB X IPE, choose the PIC32MX270F256B micro from the list, and ensure that the 'Power target circuit from tool' option is selected.

Open the HEX file (available for download from the February 2020 page of the *PE* website) and then press the Program button. Make sure you are using the appropriate HEX file depending on whether you are programming the device to operate with a keyboard or mouse; they have a different file name suffix.

Check the progress display at the bottom of the window to ensure that the firmware upload is successful.

The red LED should then illuminate, indicating that the *USB Keyboard and Mouse Adaptor* is waiting for a keyboard or mouse to be connected.

Testing

For initial testing and familiarisation with how the *USB Keyboard and Mouse Adaptor* works, we recommend that you connect it to a PC using a USB/serial converter; eg, one based on the CP2102 chip. Four wires need to be connected to CON3: 5V, GND and the two serial data lines. We have used arrows to indicate the data flow of the two serial data lines, as TX and RX markings are often ambiguous.

Connect the RX line on the USB/serial adaptor to the pin with the arrow that's pointing towards the edge of the PCB, and the TX line to the pin with the arrow that's pointing into the middle of the PCB. Then plug the USB/serial adapter module into a computer. The red LED on the board should light up.

Now plug a USB keyboard or mouse (or wireless keyboard/mouse dongle) into the socket on the PCB. After around a second, the red LED should go out and the green LED should turn on.

If you do not get the green LED lighting up, then check the construction and component values. Also, make sure that you have loaded the keyboard firmware if you are using a keyboard, and the mouse firmware if you are using a mouse.

If all is well, open up the serial terminal program of choice (PuTTY, TeraTerm Pro and the Arduino Serial Monitor all are suitable) and set the baud rate to 9600 (for the keyboard version) or 1200 (for the mouse version).

Now type on the keyboard or move the mouse. You should see data appear in the serial console.

For the keyboard version, if you press letter keys, you should see the corresponding letter. In the default mouse mode, the data which appears will probably look like gibberish. You may wish to change it to CSV mode, at least temporarily, to get more legible data (the procedure is described below).

Note that if you are using the Arduino Serial monitor and the keyboard firmware then you may not get the usual effect of the Backspace key; we found that on our system it produced a black rectangle rather than deleting the previous character.

Changing the settings

On your computer, use the serial terminal program to send a '~' character to the device. On the Arduino Serial Monitor, you may need to press Enter after typing this, to send the data.

The settings menu (Fig.3 for keyboards or Fig.4 for mouses) should appear in the terminal, and the yellow LED on the unit will light up solid to indicate that you are in settings mode.

You can change most of the settings with single keystrokes. The action is confirmed on the terminal and the menu is re-displayed with the new settings shown. These settings are not active until the 'X' key is pressed to activate them.

They can be saved to Flash with the 'S' command, in which case they will become active the next time the device restarts and the settings are loaded from Flash.

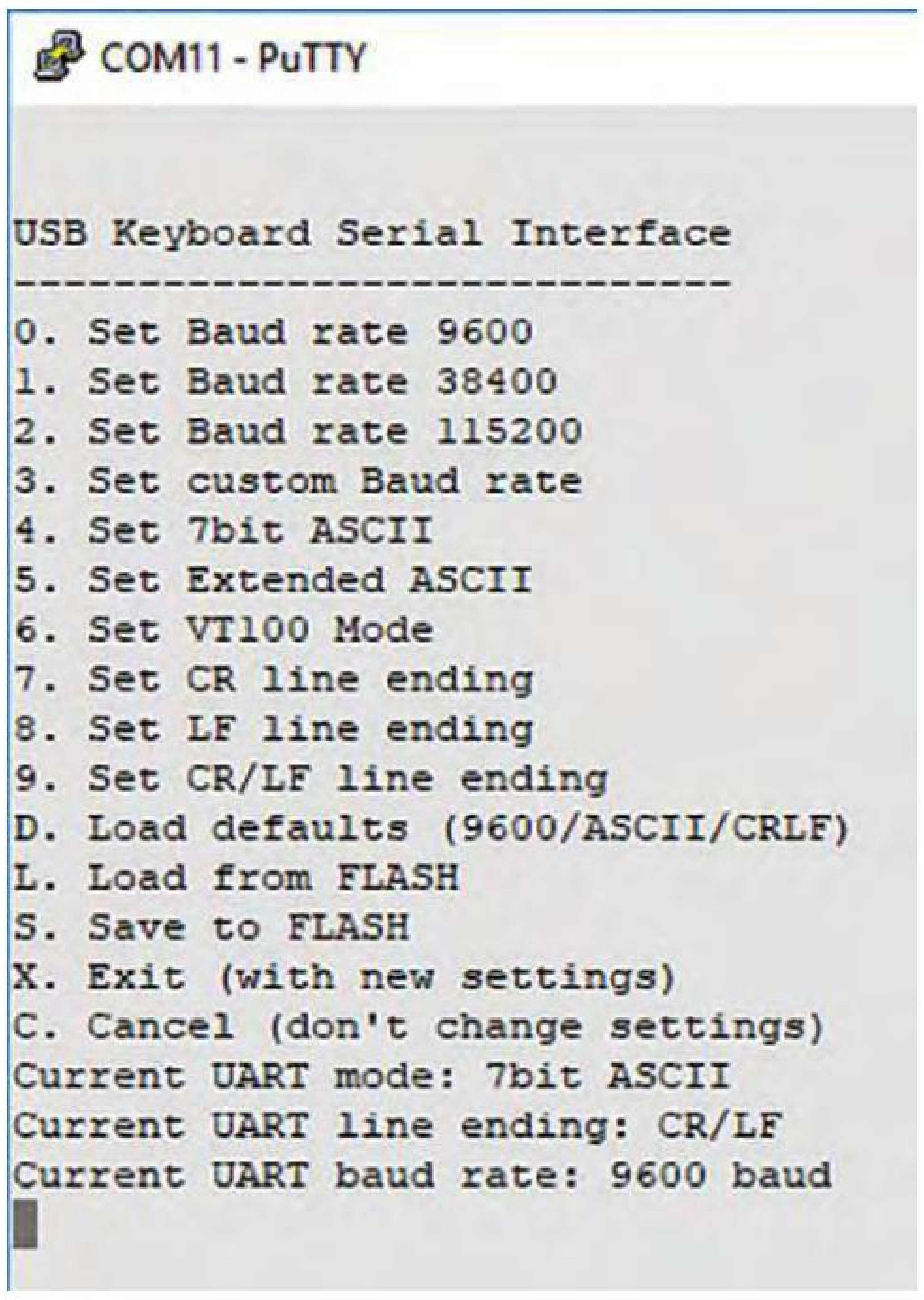
The purpose of most of the settings should be intuitive. If you change the baud rate, you will need to also change your terminal program's baud rate after pressing 'X'.

The baud rate can be set to pratically any value between 100 and 1,000,000, with a few common values such as 9600, 38,400 and 115,200 available directly from the menu.

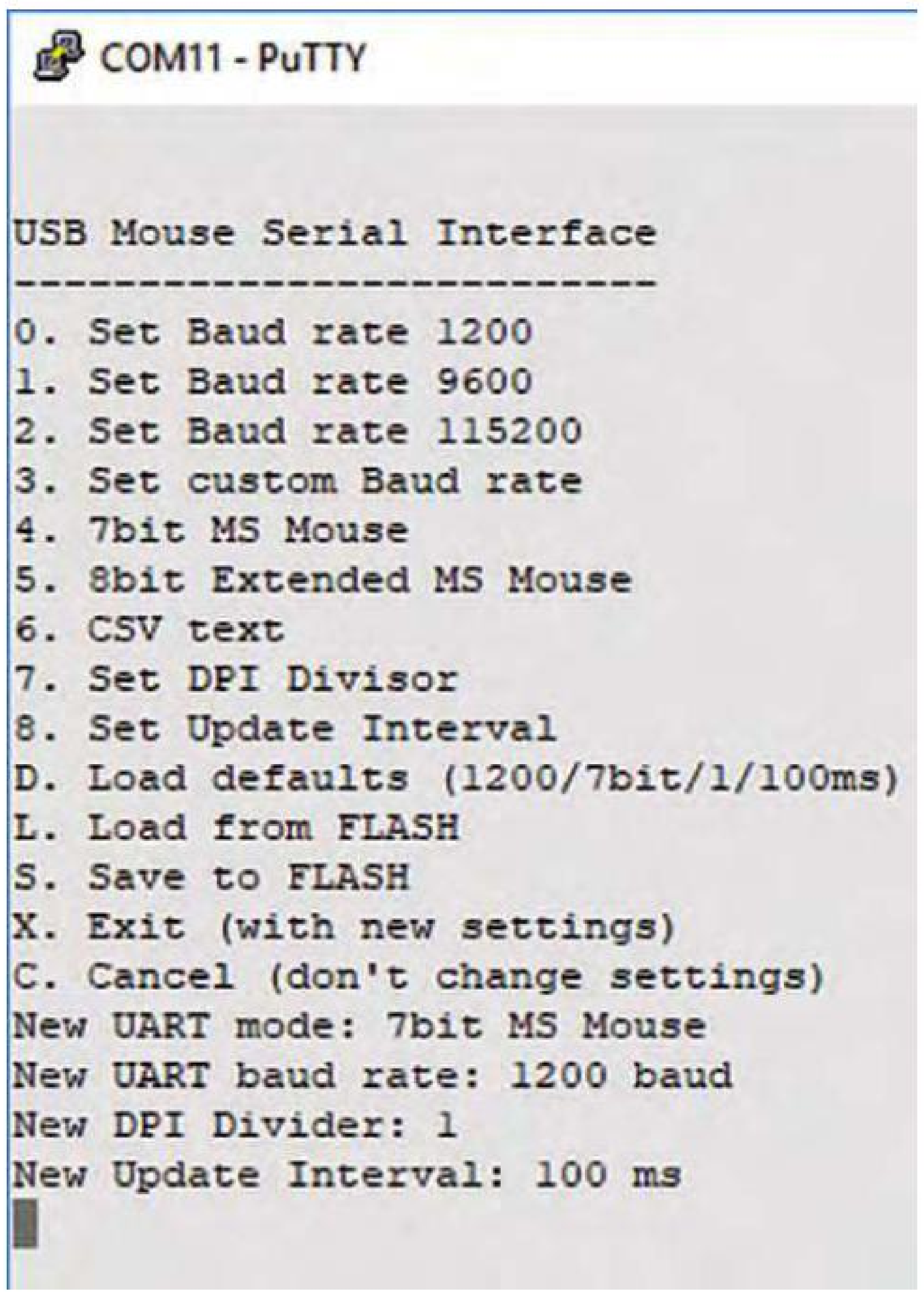
Serial data is always sent in the standard 8N1 (8 data bits, no parity, 1 stop bit) format.

As mentioned earlier, the default baud rate in keyboard mode is 9600, becuase this can easily be handled by a software serial port and it is more than fast enough for normal typing.

Fig.3: (below left) this is the settings screen of the *USB Keyboard and Mouse Adaptor* when programmed with the firmware suitable for interfacing with keyboards. If you have set a very low baud rate, it may take a few seconds for this to be displayed. The currently selected parameters are shown below the menu.



```
USB Keyboard Serial Interface
-----------------------------
0. Set Baud rate 9600
1. Set Baud rate 38400
2. Set Baud rate 115200
3. Set custom Baud rate
4. Set 7bit ASCII
5. Set Extended ASCII
6. Set VT100 Mode
7. Set CR line ending
8. Set LF line ending
9. Set CR/LF line ending
D. Load defaults (9600/ASCII/CRLF)
L. Load from FLASH
S. Save to FLASH
X. Exit (with new settings)
C. Cancel (don't change settings)
Current UART mode: 7bit ASCII
Current UART line ending: CR/LF
Current UART baud rate: 9600 baud
```



```
USB Mouse Serial Interface
--------------------------
0. Set Baud rate 1200
1. Set Baud rate 9600
2. Set Baud rate 115200
3. Set custom Baud rate
4. 7bit MS Mouse
5. 8bit Extended MS Mouse
6. CSV text
7. Set DPI Divisor
8. Set Update Interval
D. Load defaults (1200/7bit/1/100ms)
L. Load from FLASH
S. Save to FLASH
X. Exit (with new settings)
C. Cancel (don't change settings)
New UART mode: 7bit MS Mouse
New UART baud rate: 1200 baud
New DPI Divider: 1
New Update Interval: 100 ms
```

Fig.4: (above right) similarly, the settings screen shown when using the *Adaptor* in mouse mode. The default baud rate in this mode is lower (1200) for compatibility with the Microsoft Serial Mouse protocol, but you can change it if necessary. Options 4, 5 and 6 allow you to select between the three different data formats, with each mode having different capabilities – see Tables 2-4 for details.

The default baud rate in mouse mode is 1200 because that is what is used by default in the Microsoft Serial Mouse protocol, and again, it's fast enough in most cases. But you could bump it up to 9600 baud or higher, if required for your application.

If you change the keyboard mode to VT100 emulation and set your terminal emulator to VT100 mode, you should be able to use the arrow keys on the keyboard to move the cursor around the terminal and type text in various locations. That will confirm that the VT100 mode is operating correctly.

Note that instead of sending a '~' character, you can also get into the settings menu by inserting JP1. And if you change the settings and manage to get the device into a weird mode (eg, an unknown baud rate), you can temporarily switch it back to the default settings by inserting JP2.

Removing JP2 and power cycling the unit will revert it back to whatever configuration you last saved.

To permanently revert the settings back to the default (you can change them again later), place a shorting block on the JP3 header and cycle power to the unit. You can then remove the shorting block.

The default configuration values will have been written to Flash. And once you have set up the unit the way you need it, you can place a shorting block on JP4 to prevent accidental configuration changes.

Mouse-specific settings

Besides the three possible modes described above, there are two additional mouse-specific settings: the DPI Divisor (movement scaling factor) and Update Interval.

The internal mouse movement pixel count is divided by the DPI Divisor before being sent to the serial port. Some mouses report movement values which overflow some of the data formats, so this setting provides a way of scaling the movement values down to a suitable range.

You may also find that specific scaling values make it simpler to handle mouse movements in your micro firmware.

The Update Interval is specified in milliseconds. It is the minimum interval between movement updates; button press or release events are reported immediately.

The USB interface can operate at up to 125Hz – ie, 8ms between updates. If your application does not need such a high update rate or just can't

Table 2: Microsoft Serial Mouse data format

Byte	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	1	1	Left button	Right button	Y7	Y6	X7	X6
1	1	0	X5	X4	X3	X2	X1	X0
2	1	0	Y5	Y4	Y3	Y2	Y1	Y

Table 3: 8-bit Mouse data format

Byte	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	1	Left button	Right button	Middle button	Y8	Y7	X8	X7
1	0	X6	X5	X4	X3	X2	X1	X0
2	0	Y6	Y5	Y4	Y3	Y2	Y1	Y0

Table 4: CSV Mouse data format

Each entry has the form: Buttons,delta x,delta y,delta z<CR><LF>
Where Buttons is an 8-bit value:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Left Button	Right Button	Middle Button	Button 4	Button 5	0	0	0

These tables show the three data formats available when using the mouse version of the firmware. The Microsoft Serial Mouse data format is identical to that used on the Microsoft Mouse 2.0 (from 1985). How's that for backward compatibility!

handle it, you can use the update rate setting to increase the interval. We found that 100ms (giving 10Hz updates) was adequate for most of our micro-based applications.

Connecting it to your target micro

When connecting the *USB Keyboard and Mouse Adaptor* to a micro, you usually only need to run three wires. The serial receive line (next to GND on CON3) does not normally need to be connected.

If you're using an Arduino Uno or similar device, with only one hardware serial port that's already used for debugging/programming, we suggest that you configure a receive-only software serial port to connect to each *Keyboard/Mouse Adaptor*.

These are usually limited in baud rate because they use too many CPU cycles at higher baud rates. But 9600 baud is fast enough for this application and it will typically only take up a single digital I/O pin.

Ensure that the device you are connecting to has a stable 5V supply which can provide enough power to run the connected keyboard or mouse.

If your micro was already set up to receive data via a serial terminal, you can use the *Keyboard Adaptor* in 7-bit ASCII mode and simply wire it up to that terminal. You should not need to make any changes to enter commands.

Note that you may not be able to feed data directly into the serial console of a micro board if that serial port is permanently wired to a USB/Serial converter chip. That chip may override any data coming from the *Adaptor*.

In that case, you will need to use a separate serial port (hardware-based or software-based) to handle the data.

Linux terminal consoles can work in VT100 compatible mode. In the case of small single-board computers such as the Raspberry Pi, the console is often broken out to a physical UART on the GPIO header.

So the *USB Keyboard and Mouse Adaptor* can be directly connected there and set up in VT100 mode, to drive the console directly.

Similarly, if you are using the *Keyboard Adaptor* with a Micromite, you may need to do nothing more than connect it up to the serial console and configure the *Adaptor* for the correct baud rate and terminal mode.

If you are using the Micromite Plus Explore 100 with an SSD1963-based 5-inch (or larger) LCD panel, you will have a complete stand-alone system, with console text displayed on the LCD and updated via the USB keyboard.

We suggest you use VT100 mode in this case. The Explore 100 does already have a keyboard connector, but it's the ancient PS/2 type; suitable keyboards are getting hard to find.

Handling mouse and keyboard data in your software

In many cases, we expect that you will want to write specific software to interpret key presses, and this will almost certainly be the case if you are using a mouse. You will therefore need to set up one or more serial ports with the correct baud rate, wire up the board(s) to their receive pins, and then periodically check to see whether data has been received on those ports.

When data is received, your program will need to decide what action to take.

For example, it could compare the received key codes to a list of expected codes and execute a different function depending on which key is pressed.

Since the mouse data is more tricky to interpret than keyboard data, we have written a sample Arduino sketch to read and decode the mouse data. You can download it from the *PE* website, in the same download package as the firmware.

If you plan to decode the mouse data yourself, the three data format are explained in Tables 2-4.

Parts list – USB Micro Keyboard and Mouse Interface

1 double-sided PCB, 64mm x 44mm, coded 24311181, available from the *PE PCB Service*
1 5-pin vertical or right-angle header (CON1)
1 USB Type-A socket (CON2)
1 4-pin vertical or right-angle header (CON3)
1 2x4 pin header (JP1-JP4)
1 jumper shunt (JP1 *or* JP2 *or* JP3 *or* JP4)
1 16MHz HC-49/U or HC-49/US crystal (X1)

Semiconductors
1 PIC32MX270F256B-50I/SP (IC1), programmed with 2431118K.HEX (for use with a keyboard) ***or*** 2431118M.HEX (for use with a mouse)
1 1N5819 schottky diode (D1)
1 3mm red LED (LED1)
1 3mm yellow LED (LED2)
1 3mm green LED (LED3)
1 MCP1700-3.3 3.3V linear regulator, TO-92 package (REG1)

Capacitors
3 10µF 16V electrolytic
1 47µF 6V tantalum
2 22pF ceramic

Resistors (1/4W or 1/2W 1% metal film)
1 10kΩ 5 1kΩ

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Using Cheap Asian Electronic Modules Part 21: by Jim Rowe

Stamp-sized digital audio player

The DFPlayer Mini is a low-cost digital audio player module. It's available from popular Internet suppliers, including uk.banggood.com and Amazon.co.uk, as well as marketplaces like eBay and AliExpress, for a couple of pounds, including postage. Despite its size and price, it can do a lot!

The DFPlayer Mini is a very flexible module with a great many features. I was impressed after trying the module out for myself.

One of the best things about it is that it plays several different audio file formats, including MP3, WMA and WAV, in mono or stereo, and it can read those files off either a microSD card or USB Flash drive with a capacity up to 32GB in either case. But it has a lot of other features, so let's take a look at the hardware involved and how to drive it.

What's inside the module

Circuit diagrams for the *DFPlayer Mini* module are surprisingly hard to find, but an examination of the module reveals that it's based on two ICs: a YX5200-24SS (IC1) which does most of the work and a smaller 8002 audio amplifier chip (IC2).

While data sheets for both devices are available, the sheet for the YX5200-24SS is almost entirely in Chinese. But I was able to glean enough info to draw the module's internal block diagram, shown in Fig.1.

The YX-5200 chip is the module's brains. Inside it, there's a 16-bit MCU (micrcontroller), an analogue DSP (digital signal processor), EPROM and Flash memory, a 24-bit stereo DAC (digital-to-analogue converter), a serial UART for communication with an external MCU, and ports to communicate with a microSD card or a USB thumb drive.

All this in a compact 24-pin SSOP (SMD) package – it's virtually a complete digital audio system on a chip!

The YX-5200 chip can play back MP3, WMA and WAV files at sampling rates of 8kHz, 11.025kHz, 12kHz, 16kHz, 22.05kHz, 24kHz, 32kHz, 44.1kHz or 48kHz.

It can handle files on either microSD ('TransFlash' or TF) cards or USB thumb drives with capacities up to 32GB, formatted with a FAT16 or FAT32 file system.

You can store up to 45 hours of CD-quality WAV files on a 32GB card/drive, or about 23-days worth of 128kbit MP3 files – a lot!

The 24-bit stereo DAC in the YX-5200 is claimed to provide a dynamic range of 90dB, with a signal-to-noise ratio (SNR) of 85dB. That isn't exactly HI-Fi, but it isn't too bad either.

The built-in MCU and DSP combine to provide features like audio gain adjustment over 31 levels and the ability to select one of six playback tonal equalisation settings.

You can also select the playback mode (normal/repeat/folder repeat/single repeat/random) and the playback source (USB drive, microSD card or a couple of other options).

It also provides a BUSY logic output signal which is at logic-low level (<800mV) when playing a file, rising to logic high (~3.5V) when playback stops.

Turning to IC2, its operation is quite straightforward. Housed in an 8-pin SOIC package, it's basically just a low-power audio amplifier with a few extras.

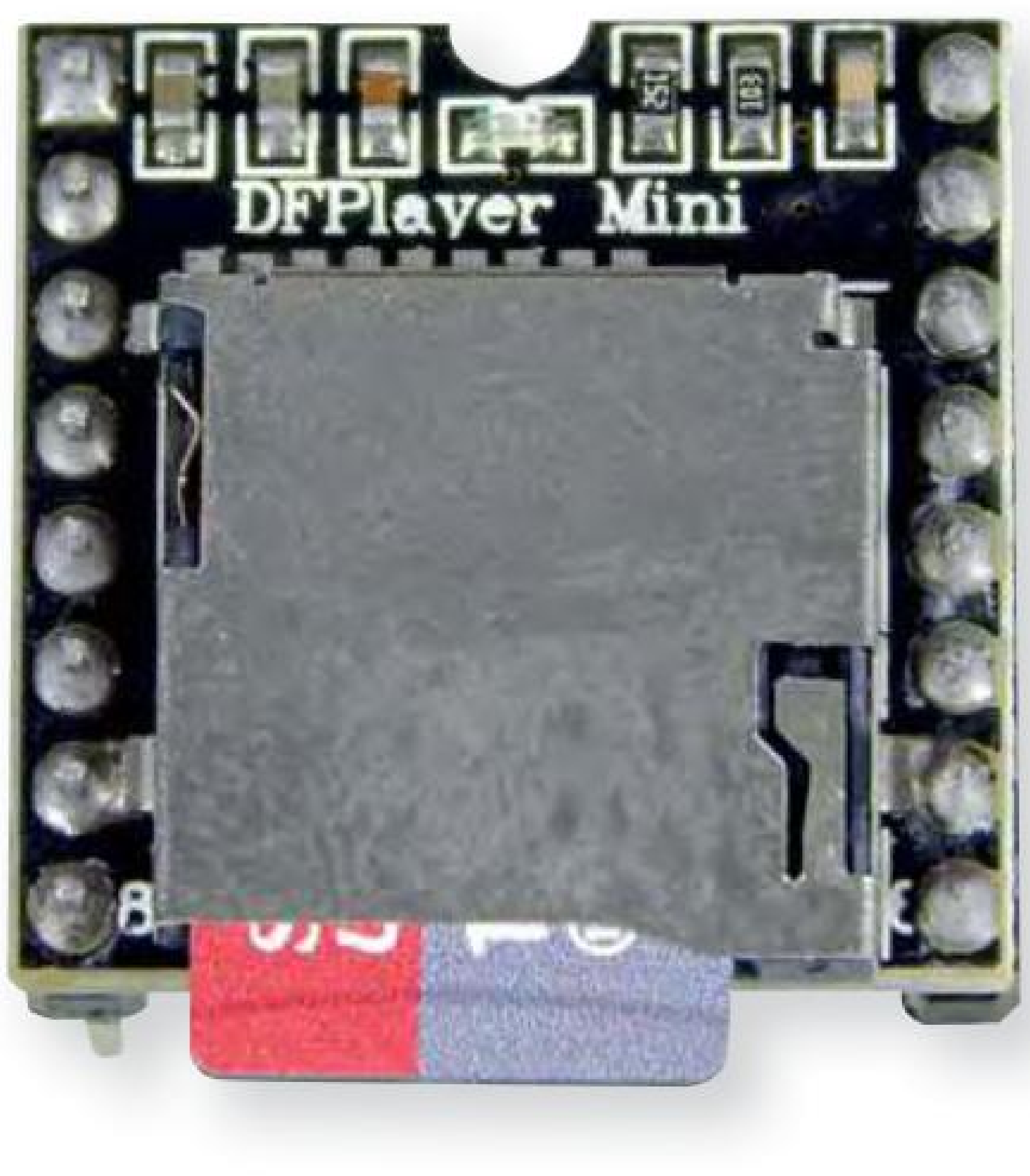
Running from 5V, it can deliver up to 2W into a 4Ω loudspeaker load with 10% total harmonic distortion (THD+N), or 1.5W into an 8Ω load with 1% THD+N.

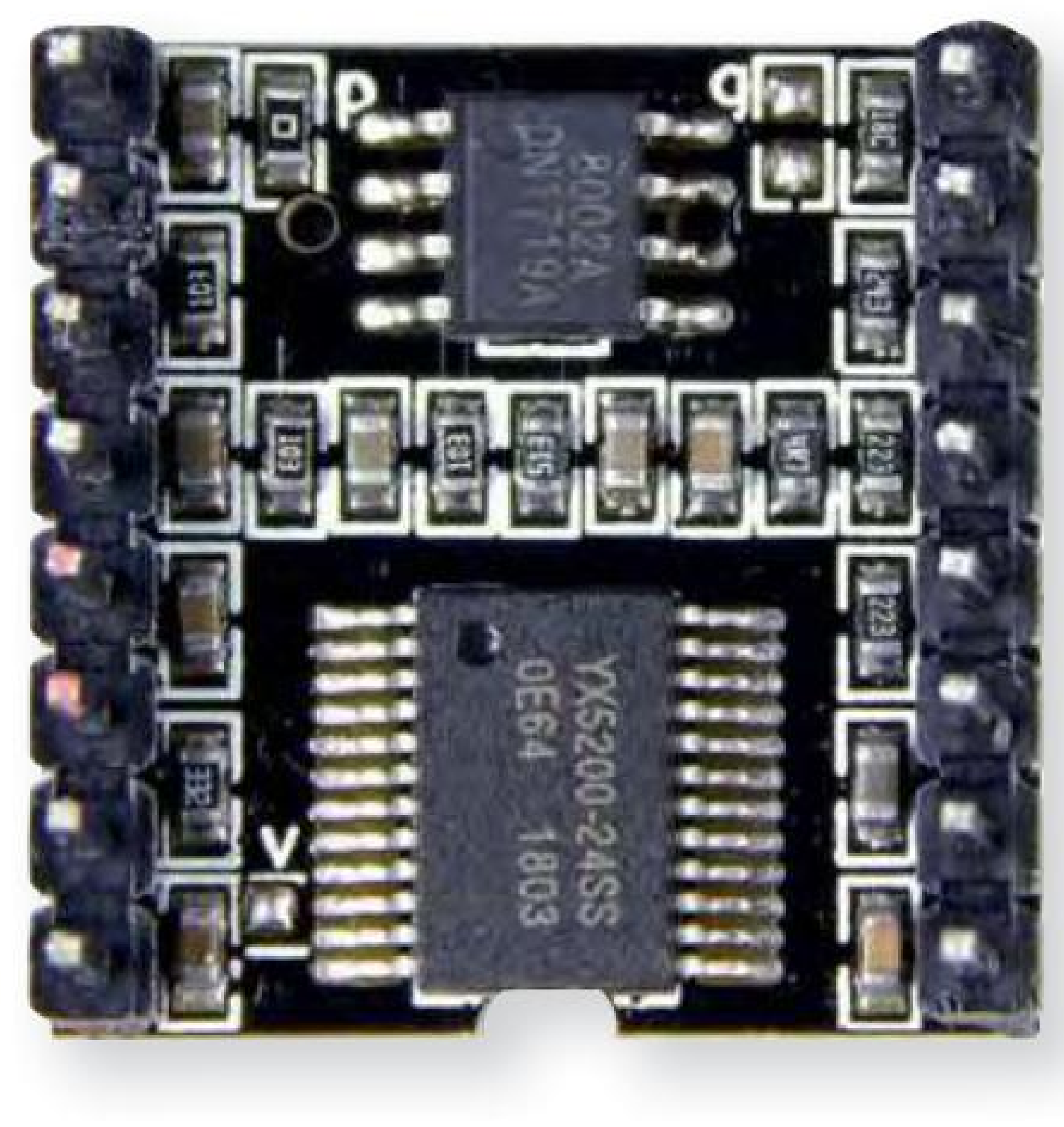
It provides a push-pull (bridged) output, and no output coupling capacitors, snubber network or bootstrap capacitors are needed. It's also unity-gain stable, has an externally programmable gain and includes circuitry to suppress clicks and plops during power on/off.

As you can see from Fig.1, the *DFPlayer Mini* module makes good use of the many features provided by both ICs.

As well as providing all of the main control inputs needed by IC1, it also features a microSD card socket on the top of the module connected directly to IC1. The latter's BUSY signal output is brought out to a pin and also drives LED1, a tiny blue SMD LED.

The left and right channel outputs from the YX5200's DAC are also





Views of the top (left) and bottom of the *DFPlayer Mini* module with a microSD card inserted. It is shown at close to double life size for clarity.

Features and specifications

- Just 21 × 21 × 12mm including microSD card socket and pin headers
- Plays MP3, WMA and WAV audio files (4.3 filenames)
- 24-bit stereo DAC
- Built-in 2W mono bridge-mode amplifier
- Plays files from microSD cards or USB Flash drives (up to 32GB)
- Multiple control options, from just four pushbutton switches to full serial mode control from a microcontroller (eg, Arduino or Micromite)
- Line-level stereo outputs which can also drive headphones
- Six playback equalisation options: Normal (flat), Pop, Rock, Jazz, Classical and Bass
- Programmable playback volume in 31 steps (0-30)
- Runs from a 3.3-5.2V supply, drawing 25mA when idle or 200-250mA during playback.

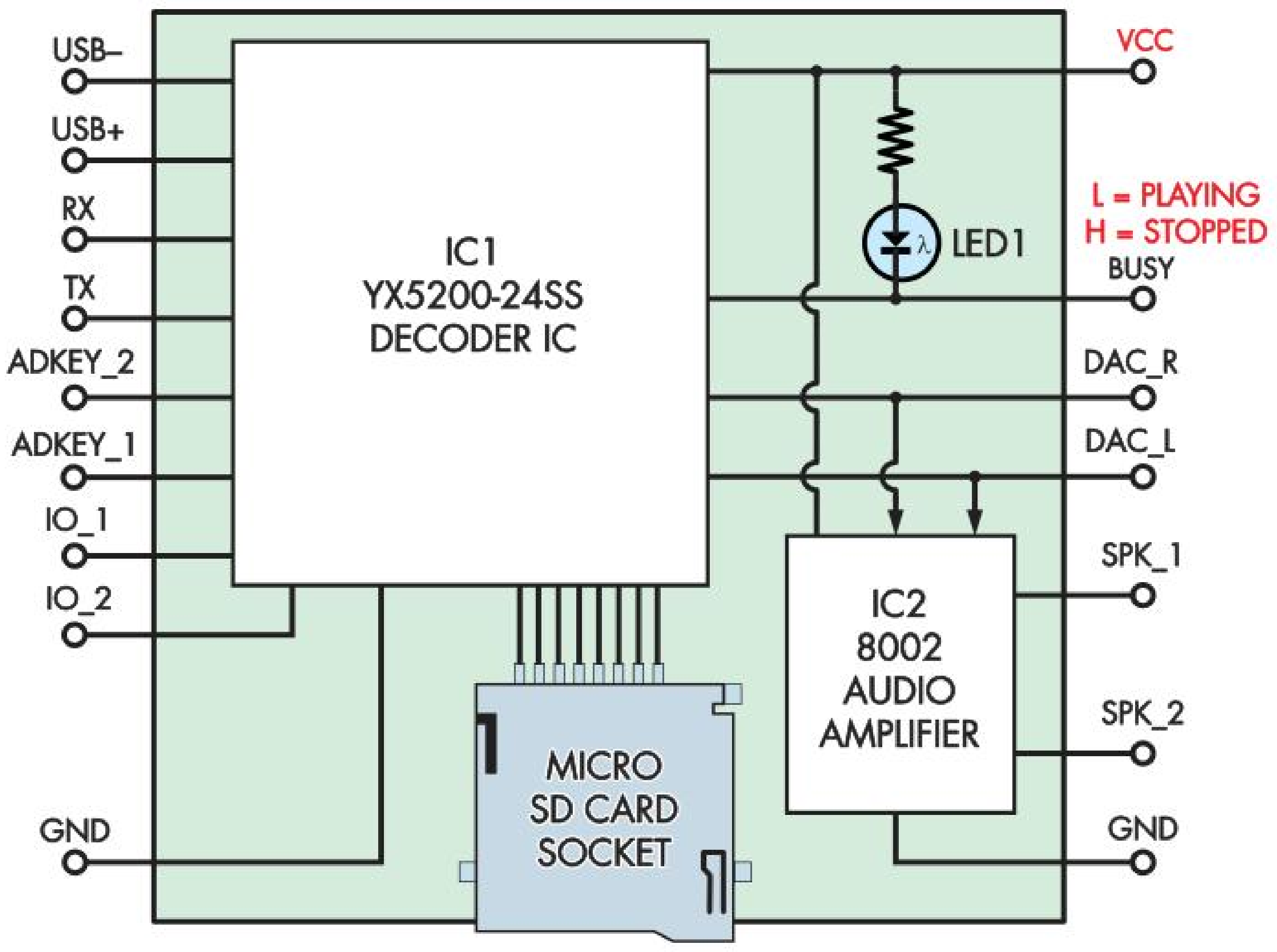

USB–
USB+
RX
TX
ADKEY_2
ADKEY_1
IO_1
IO_2
GND
IC1
YX5200-24SS
DECODER IC
LED1
VCC
L = PLAYING
H = STOPPED
BUSY
DAC_R
DAC_L
SPK_1
IC2
8002
AUDIO
AMPLIFIER
SPK_2
GND
MICRO
SD CARD
SOCKET

Fig.1: block diagram of the *DFPlayer Mini* audio player module.

brought out for use in driving either headphones or an external amplifier, in addition to being mixed together and fed into IC2 to drive a speaker directly.

No socket is provided for plugging in a USB thumb drive – just a couple of pins identified as 'USB–' and 'USB+'. I couldn't find any information on the use of these pins anywhere in the commonly available data sheets for the *DFPlayer Mini* module, but I guessed that these could be connected to the D– and D+ signal lines of a USB socket, and as you will see later, I was right.

Putting it to use

Fig.2 shows how to wire up the *DFPlayer Mini* module. The speaker (if used) connects directly between the SPK_1 and SPK_2 pins (6 and 8) while the module's power supply (3.3-5.2V DC) is fed to pin 1 (V_{CC}) and pins 7/10 (GND).

The total current requirement is around 25mA when idle, rising to around 200-250mA during playback.

The module can be used as a self-contained audio player, controlled using just four SPST pushbutton switches, connected as shown in Fig.3. Alternatively, a much larger array of 20 pushbuttons can be connected, as shown in Fig.4.

Otherwise, its operation can be controlled entirely from an Arduino, a Micromite or many other kinds of microcontroller, using the UART serial port lines at pins 2 (RX) and 3 (TX), along with the $\overline{\text{BUSY}}$ signal from pin 16. This configuration is shown in Figs.5 and 6.

The rest of the connections are to make use of the module's extra features.

For example, you can use it to play files from a USB thumb drive by connecting up a Type A USB socket as shown at the top right of Fig.2, with pin 1 connected to the +5V supply, pins 2 and 3 to pins 15 (USB–) and 14 (USB+) of the module, and pin 4 to the module ground (pins 7 or 10).

The dashed connections to pins 4 (DAC_R) and 5 (DAC_L) of the module show how it can be used to drive either stereo headphones or line-level outputs to an external stereo amplifier or HI-Fi system.

Returning now to Fig.3, which shows the simple four-pushbutton control scheme, S1 and S2 have dual functions in this mode. A short press is used to move to the previous track (S1) or the next track (S2), while a longer press either decreases (S1) or increases (S2) the volume. S3 and S4 each have only single functions, to start playing the first track (S3), or the fifth track (S4).

The more complex pushbutton control arrangement of Fig.4 is a bit more tricky. To allow twenty pushbuttons to be connected using just two pins, each

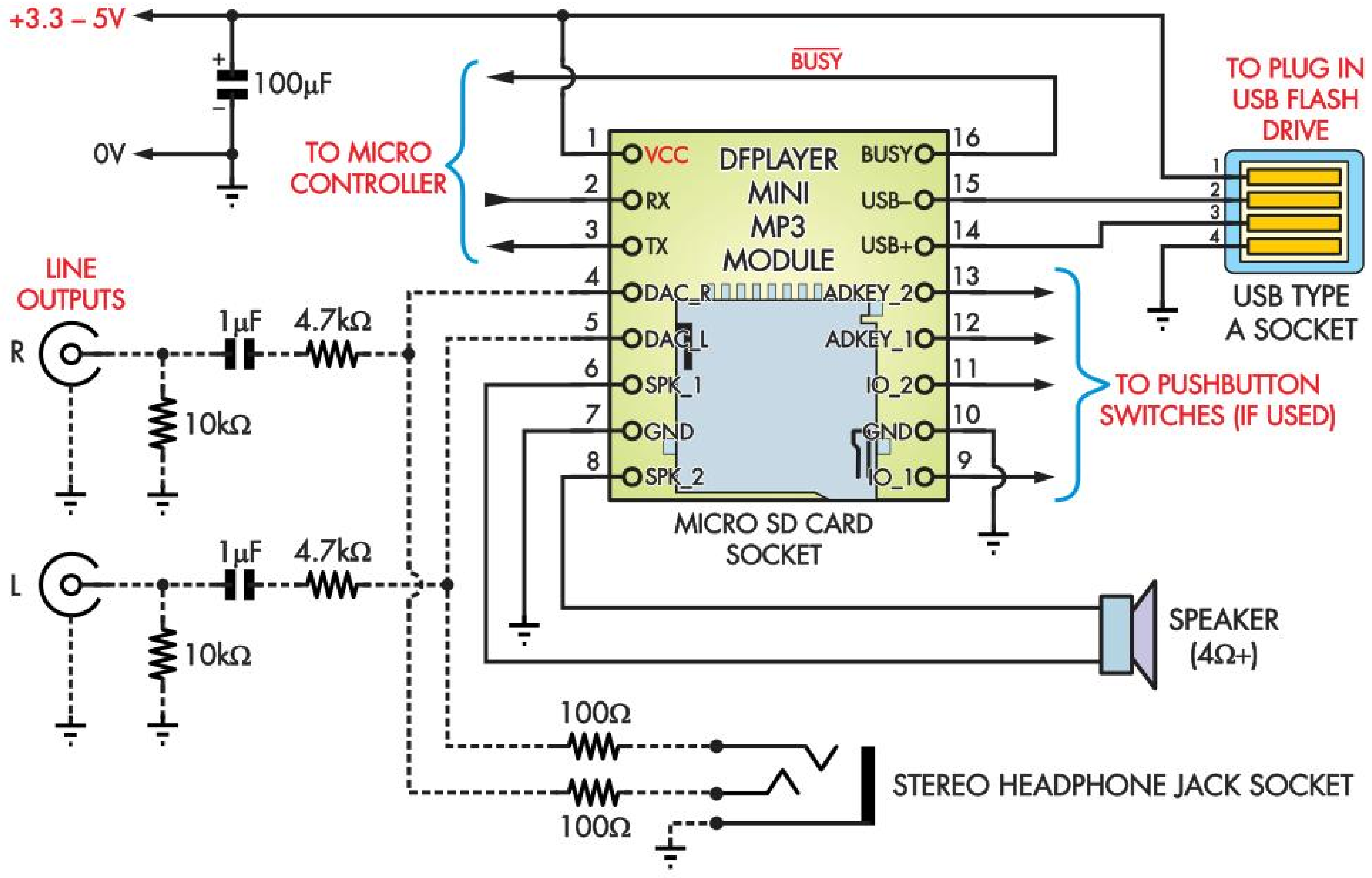
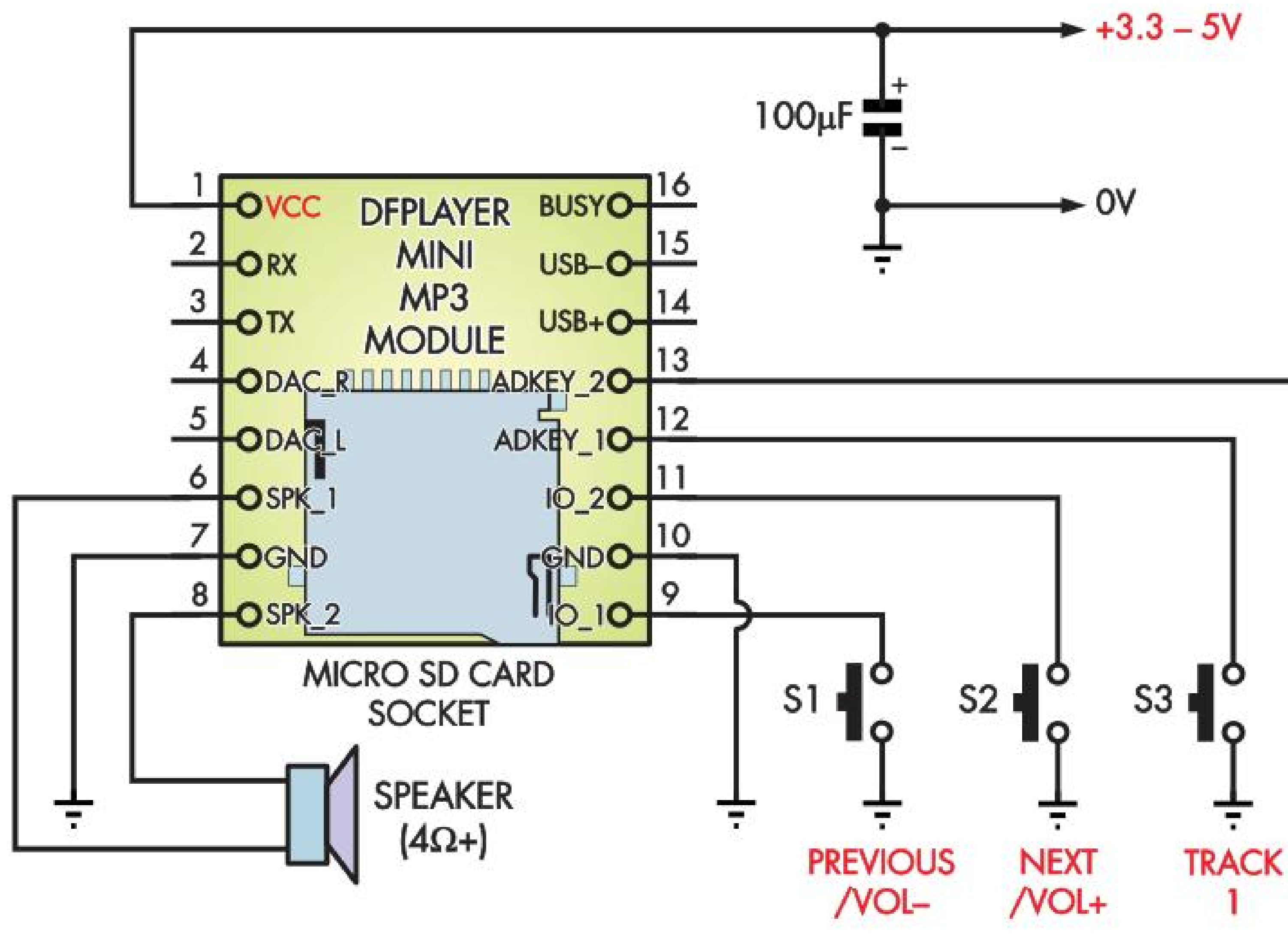

+3.3 – 5V
100µF
0V
TO MICRO
CONTROLLER
BUSY
1
VCC
RX
TX
DAC_R
DAC_L
SPK_1
GND
SPK_2
DFPLAYER
MINI
MP3
MODULE
BUSY
USB–
USB+
ADKEY_2
ADKEY_1
IO_2
GND
IO_1
16
15
14
13
12
11
10
9
2
3
4
5
6
7
8
TO PLUG IN
USB FLASH
DRIVE
1
2
3
4
USB TYPE
A SOCKET
LINE
OUTPUTS
R
L
1µF
4.7kΩ
10kΩ
1µF
4.7kΩ
10kΩ
TO PUSHBUTTON
SWITCHES (IF USED)
MICRO SD CARD
SOCKET
SPEAKER
(4Ω+)
100Ω
100Ω
STEREO HEADPHONE JACK SOCKET

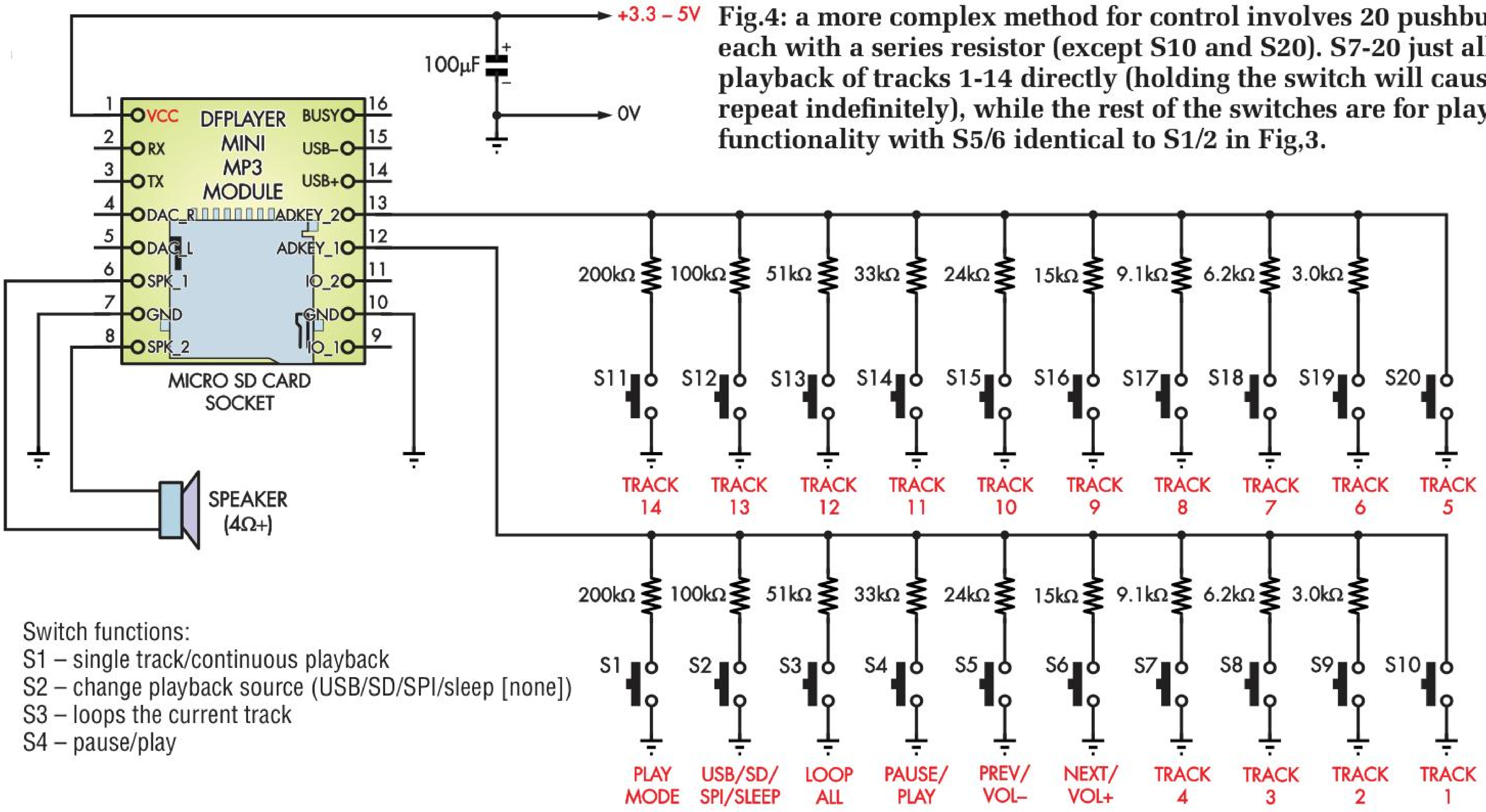
Fig.2: This shows how to connect the audio player module for playback to a speaker, headphones or other audio devices via the level outputs.


+3.3 – 5V
100µF
0V
1
VCC
2
RX
3
TX
4
DAC_R
5
DAC_L
6
SPK_1
7
GND
8
SPK_2
DFPLAYER
MINI
MP3
MODULE
BUSY
16
USB–
15
USB+
14
ADKEY_2
13
ADKEY_1
12
IO_2
11
GND
10
IO_1
9
MICRO SD CARD
SOCKET
SPEAKER
(4Ω+)
S1
S2
S3
S4
PREVIOUS
/VOL–
NEXT
/VOL+
TRACK
1
TRACK
5

Press S1: previous track
Hold S1: increase volume
Press S2: next track
Hold S2: decrease volume
Press S3: play first track
Press S4: play fifth track

Fig.3: the simplest method of controlling the *DFPlayer Mini* module is by using four pushbutton switches. Track 5 is equivalent to 005.mp3 (four characters at most for a filename, three for the extension); folders are named 01 to 99.

Fig.4: a more complex method for control involves 20 pushbuttons, each with a series resistor (except S10 and S20). S7-20 just allows playback of tracks 1-14 directly (holding the switch will cause it to repeat indefinitely), while the rest of the switches are for playback functionality with S5/6 identical to S1/2 in Fig,3.


+3.3 – 5V
100µF
0V
VCC
DFPLAYER MINI MP3 MODULE
RX
TX
DAC_R
DAC_L
SPK_1
GND
SPK_2
BUSY
USB–
USB+
ADKEY_2
ADKEY_1
IO_2
GND
IO_1
MICRO SD CARD SOCKET
SPEAKER (4Ω+)
200kΩ
100kΩ
51kΩ
33kΩ
24kΩ
15kΩ
9.1kΩ
6.2kΩ
3.0kΩ
S11
S12
S13
S14
S15
S16
S17
S18
S19
S20
TRACK 14
TRACK 13
TRACK 12
TRACK 11
TRACK 10
TRACK 9
TRACK 8
TRACK 7
TRACK 6
TRACK 5
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
PLAY MODE
USB/SD/ SPI/SLEEP
LOOP ALL
PAUSE/ PLAY
PREV/ VOL–
NEXT/ VOL+
TRACK 4
TRACK 3
TRACK 2
TRACK 1
Switch functions:
S1 – single track/continuous playback
S2 – change playback source (USB/SD/SPI/sleep [none])
S3 – loops the current track
S4 – pause/play

of the ten pushbuttons in a given 'bank' has a different resistor value connected in series.

The chip then measures the current sunk from pin 12 or 13 when a button is pressed, and depending on what range it is in, it knows which button was pressed.

In this mode, most of the extra switches (S7–S20) are simply used to allow direct selection of tracks to play.

Switches S5 and S6 basically duplicate the actions of S1 and S2 in Fig.3, while the first four switches (S1–S4) allow control over the playback mode (single track/continuous), playback source (USB/SD/SPI/SLEEP), enable 'loop all' mode and provide the pause/play function.

Controlling it with a micro

Hooking the *DFPlayer Mini* up to a microcontroller is simple, thanks to the module's built-in UART serial port. You just need to connect the module's RX input (pin 2) to the serial TX output of the micro and connect the module's TX output (pin 3) to the serial RX input of the micro. The GND of the module (pin 7 and/or 10) also needs to be connected to the micro's ground network.

The module's UART is pre-programmed to communicate at 9600 baud, with the basic 8N1 protocol. It's also a good idea to link the module's $\overline{\text{BUSY}}$ output (pin 16) to a digital input on the micro so that the control program can tell whether the module is playing a file or has stopped.

Arduino specifics

Fig.5 shows the connections for controlling the module from an Arduino. It's powered from the Arduino's 5V supply, which is fed to its V_{CC} pin (pin 1). For serial communications, we're using Arduino digital I/O pins 10 and 11, which are driven by the SoftwareSerial library code.

The D11 digital output is connected to the RX pin on the module via a 1kΩ series resistor. That's because the module inputs can handle a 3.3V signal while the Arduino pins have a 5V swing.

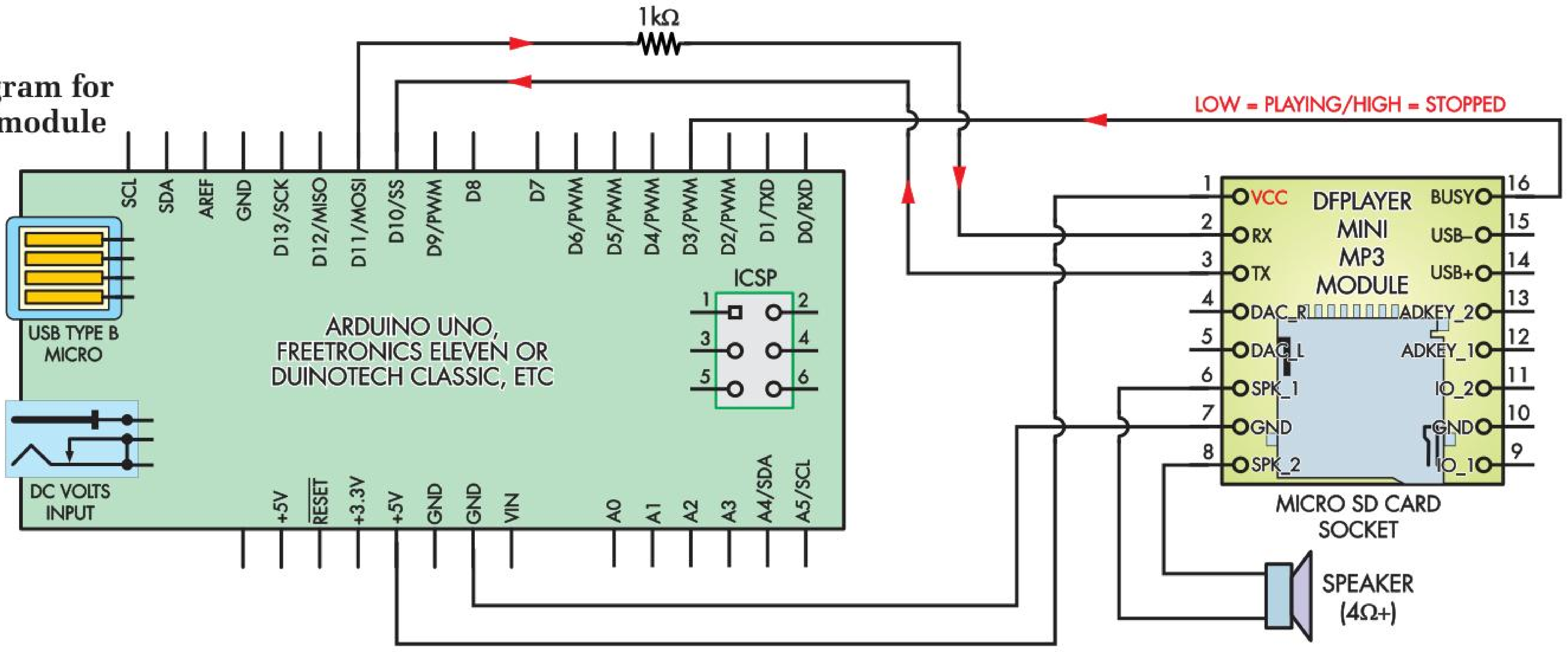
The resistor limits the current into the module's RX pin to a reasonable level (less than 2mA) when D11 is driven high. The only other connection needed is between pin 16 of the module ($\overline{\text{BUSY}}$) and D3 of the Arduino, for the reasons described above.

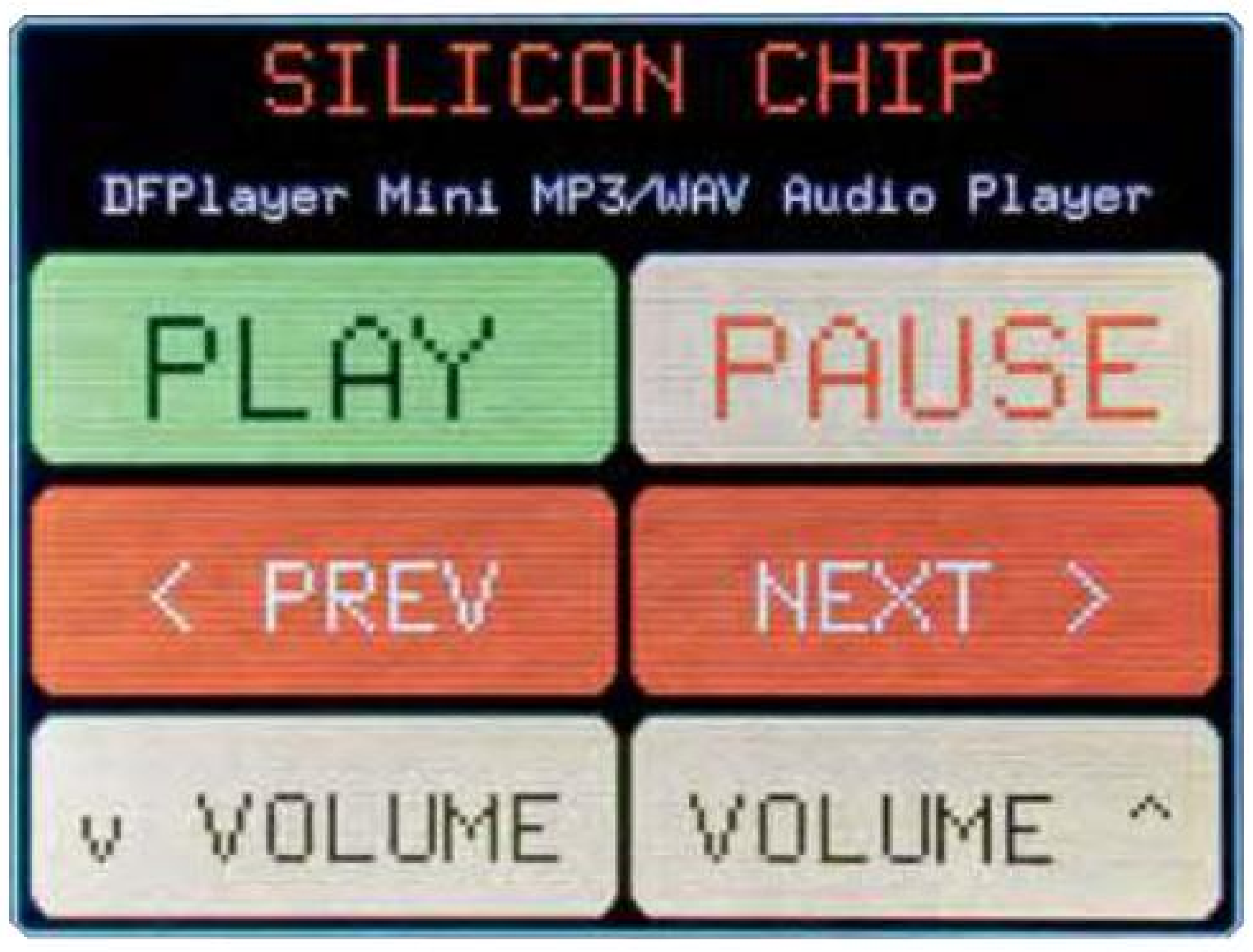
For clarity, Fig.5 does not show, for example, a USB socket, headphone socket or line outputs, which were shown in Fig.2. But these can certainly be included if you need those functions.

There are many different libraries and sketches on the Internet which show how to drive the *DFPlayer Mini* from an Arduino, although some are a bit flakey and/or hard to understand.

But one of the best is from the manufacturers themselves, DFRobot and is called **DFRobotDFPlayerMini-1.0.3.zip** – it includes a set of example sketches and you will find a link to download it below.

Fig.5: wiring diagram for the audio player module when connected to an Arduino.


1kΩ
LOW = PLAYING/HIGH = STOPPED
SCL
SDA
AREF
GND
D13/SCK
D12/MISO
D11/MOSI
D10/SS
D9/PWM
D8
D7
D6/PWM
D5/PWM
D4/PWM
D3/PWM
D2/PWM
D1/TXD
D0/RXD
ICSP
USB TYPE B MICRO
ARDUINO UNO, FREETRONICS ELEVEN OR DUINOTECH CLASSIC, ETC
DC VOLTS INPUT
+5V
RESET
+3.3V
+5V
GND
GND
VIN
A0
A1
A2
A3
A4/SDA
A5/SCL
VCC
DFPLAYER MINI MP3 MODULE
RX
TX
DAC_R
DAC_L
SPK_1
GND
SPK_2
BUSY
USB–
USB+
ADKEY_2
ADKEY_1
IO_2
GND
IO_1
MICRO SD CARD SOCKET
SPEAKER (4Ω+)


SILICON CHIP
DFPlayer Mini MP3/WAV Audio Player
PLAY
PAUSE
< PREV
NEXT >
v VOLUME
VOLUME ^

Screenshot of the MMBasic example program running on a Micromite.

Driving it from a Micromite

If you're one of the many Micromite enthusiasts, Fig.6 shows the basic connections needed to control the *DFPlayer Mini* module from a *Micromite Backpack*.

The arrangement is very similar to that for the Arduino. The module's RX (2) and TX (3) pins are connected to pins 9 and 10 of the Micromite respectively, again with a 1kΩ series resistor in series with the line to the module's RX pin.

Pins 9 and 10 of the Micromite are the TX and RX pins for the Micromite's COM2 serial port. The remaining connection is from the $\overline{\text{BUSY}}$ pin (16) of the module to pin 24 of the Micromite, again to provide a playing/not playing signal. And again, for clarity, Fig.6 leaves out any extra connections you may wish to make to the *DFPlayer Mini* module, like those shown in Fig.2.

I couldn't find any pre-existing Micromite programs to control a *DFPlayer Mini*, so I wrote one myself, after studying the YX5200-24SS data sheet and some Arduino library files. The program is called **DFPlayerMini control program.bas** and is available from the February 2020 page of the *PE* website.

It's designed to run on the *LCD BackPack* (see May 2017 and May 2018).

As you can see from the screen grab of the LCD touchscreen, the program gives you a set of six touch buttons labelled PLAY, PAUSE, PREV, NEXT, VOLUME (down) and VOLUME (up). Touching any of these buttons makes the Micromite send a command to the module to achieve the desired response, similarly to how the hardware switches shown in Fig.3 work.

Now this MMBasic program is pretty simple, but it should give you a good starting place for writing more elaborate programs yourself. With the technical information on the *DFPlayer Mini* module in this article, you should be able to get the module performing all kinds of impressive tricks!

Handy links

Module information and software:
http://bit.ly/pe-feb20-dfp1
Software library and sketches:
http://bit.ly/pe-feb20-dfp2
Documentation and Arduino library:
http://bit.ly/pe-feb20-dfp3

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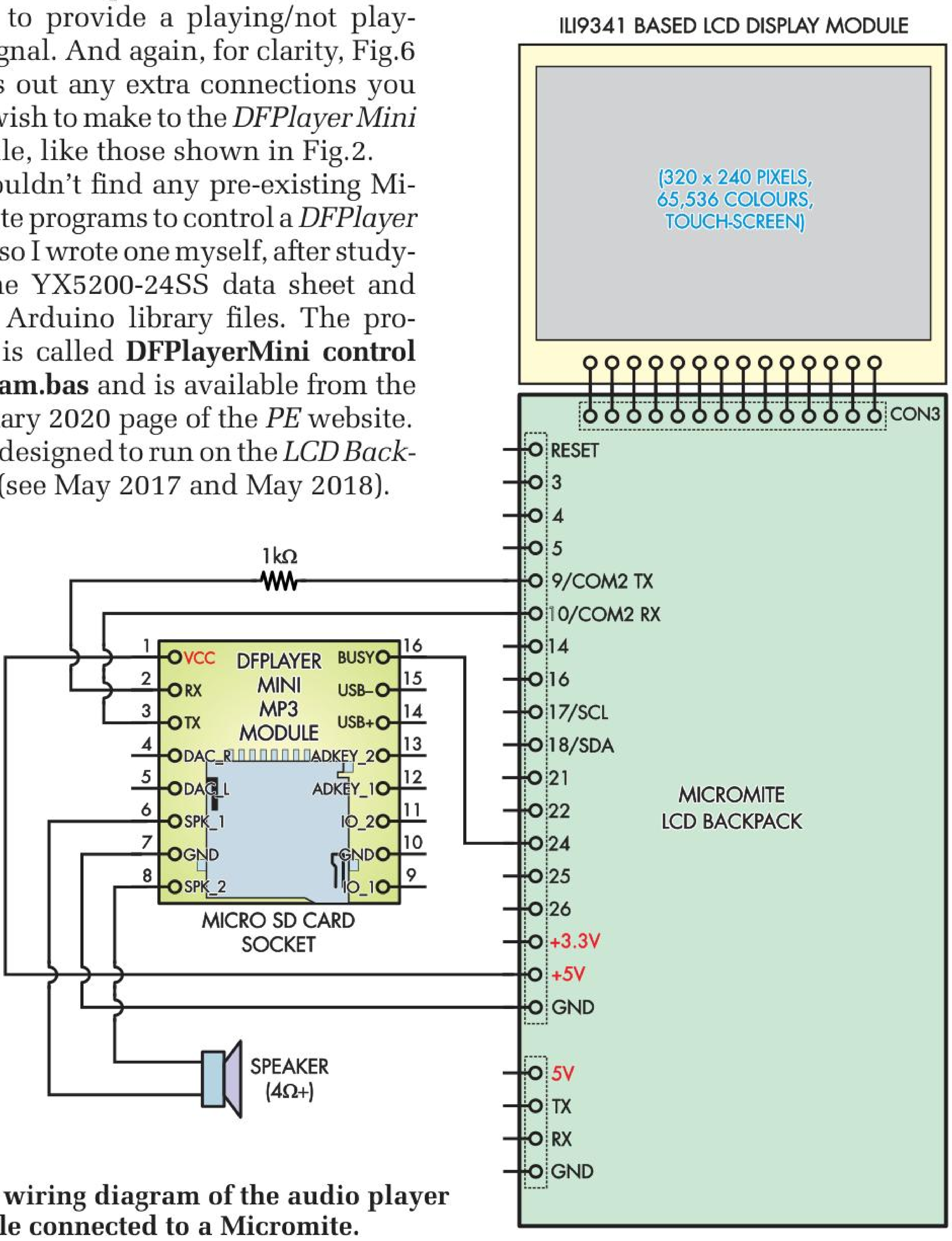
ILI9341 BASED LCD DISPLAY MODULE
(320 x 240 PIXELS, 65,536 COLOURS, TOUCH-SCREEN)
CON3
RESET
3
4
5
9/COM2 TX
10/COM2 RX
14
16
17/SCL
18/SDA
21
22
24
25
26
+3.3V
+5V
GND
5V
TX
RX
GND
MICROMITE LCD BACKPACK
1kΩ
1 VCC
2 RX
3 TX
4 DAC_R
5 DAC_L
6 SPK_1
7 GND
8 SPK_2
DFPLAYER MINI MP3 MODULE
16 BUSY
15 USB–
14 USB+
13 ADKEY_2
12 ADKEY_1
11 IO_2
10 GND
9 IO_1
MICRO SD CARD SOCKET
SPEAKER (4Ω+)

Fig.6: wiring diagram of the audio player module connected to a Micromite.

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For more information or software download please visit
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- Lowest power consumption
- Smallest and lightest
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Colour Maximite Computer

COLOUR
MAXIMITE
MAXIMITE
SD
COLOUR MAXIMITE
BLIT DEMONSTRATION

Words: Phil Boyce
Design: Geoff Graham

Part 4

A retro 80s home computer with modern-day features

Graphics capabilities, demo programs and hardware control

In Part 3, we covered the three *Maximite* modes: Immediate, Editor, and Run (and how to switch between them) allowing you to test commands, enter code, or run a program. We also showed how to save and load a program from the SD card – this included running the game *Donut Dilemma*, which demonstrated just how versatile MMBASIC really is. In this final part of the project we will work through a number of other demo programs; some will show the graphics capabilities of the *Colour Maximite Computer*, and others will challenge you, with some fun thrown in! We will finish by explaining how to access the GPIO pins to control external hardware, with a quick practical project: the *Maximite Mood Light*.

The topics covered this month are deliberately kept at a high level because we want you to explore your *Colour Maximite Computer*. Do download the *User Manual* (**http://geoffg.net/maximite.html**) – it contains extra detail and useful examples of hardware interfacing.

This month's download

There are many programs that we will be referencing and using in this final part of the *Colour Maximite Computer* project, so this month's download contains more files than usual. Start by downloading the **CMC_DemoPrograms** folder from the February 2020 page of the *PE* website. Unzip the folder, and then copy the contents (comprising multiple files and directories) directly onto your SD card. Next, power up your *Maximite*, insert your SD card, and you will see the usual flashing cursor (command prompt) meaning that the *Maximite* is in Immediate mode and waiting for a command to be entered. To check that your SD card has been prepared correctly, type `FILES` (`Enter`) and you should see a list of folders (shown as a list of `<DIR>` *`folder_name`*) followed by a list of files (`.bas`, `.fnt`, `.spr`, `.mod`, `.txt`) listed alphabetically. If you don't see this, then make sure you correct things before proceeding.

At various points throughout this article, we will reference a specific program (by filename) that you need to run. Before you run the program you will first need to locate the appropriate `.bas` file (the `.bas` extension means program code). There are two possible scenarios:

1. It is in the initial `FILES` list when you first power up the *Colour Maximite Computer* – think of this as the 'root folder'
2. It is in a dedicated folder (`<DIR>`) which has a folder name similar to the filename (more on this shortly).

Taking these two scenarios in turn:

1. Some programs will comprise just a `.bas` file. These are typically found in the root folder – try it now by typing `FILES` (`Enter`) and check that you can see `MODES.BAS`
2. Several of the demo programs require extra support files such as sprites (`.spr`), bitmaps (`.bmp`), fonts (`.fnt`), and/or sounds (`.mod`) – this is in addition to the `.bas` file. To keep things tidy, these multi-file programs have all of the required files inside their own dedicated folder (shown as `<DIR>` *`folder_name`* when you type `FILES` in the root folder). So in order to locate the `.bas` file for a multi-file program, you will first need to switch to the relevant folder with the change-directory command, `CHDIR` *`folder_name`* (as we did last month when running the *Donut Dilemma* game from the `DONUT` folder). Typing `FILES` (`Enter`) shows you all the files that make up the multi-file program. To return back to the root folder, type `CHDIR ..` (`Enter`). In effect, this goes up a folder level. An alternative is to simply reset the *Maximite* (power off, then back on) – by default, the root folder is always accessed first.

Once you have located the relevant `.bas` file, you could run the program by typing (at the command prompt) `LOAD "`*`filename`*`.bas"` (`Enter`), and then `RUN` (`Enter`). However, MMBASIC lets you shorten this by typing `RUN` *`filename`* (`Enter`). Note that the double quotes around the filename can be omitted, as well as the `.bas` file extension.

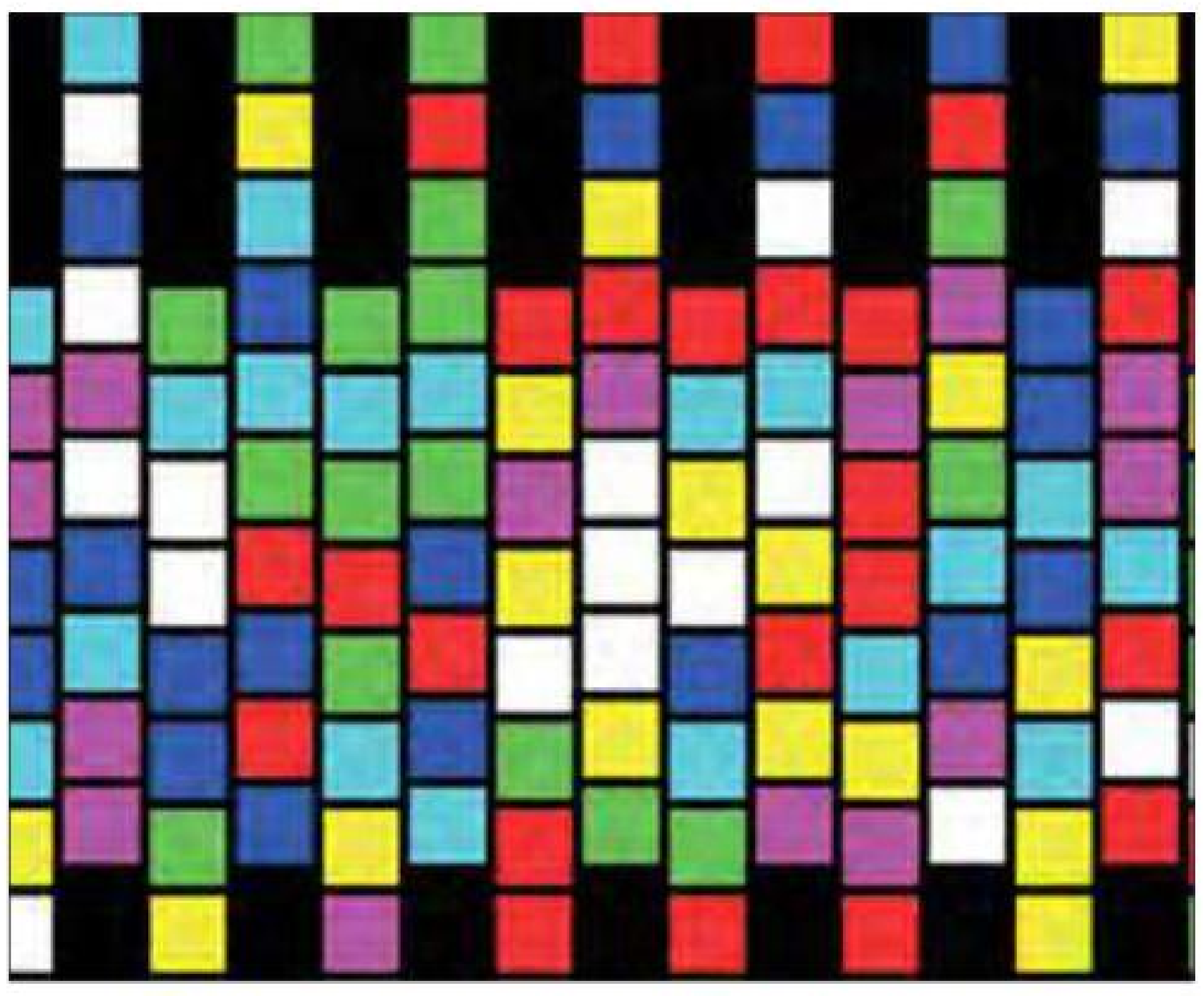
Please note that some programs will use screen `MODE 4` (240 × 216 pixels) and/or different-sized font characters. This can mean that when you stop the program and return to the command prompt (`Ctrl-C`), the characters that appear on the screen will be much bigger than normal. Typing `MODE 3`

(`Enter`) will generally return the characters to normal size – alternatively, reset the *Maximite* by temporarily removing power (or by typing `WATCHDOG 1` to reset the processor).

All this may seem a bit confusing at first, but all we're doing here is keeping things tidy on the SD card. After running the first few programs from this month's article, things will become very straightforward – I promise!

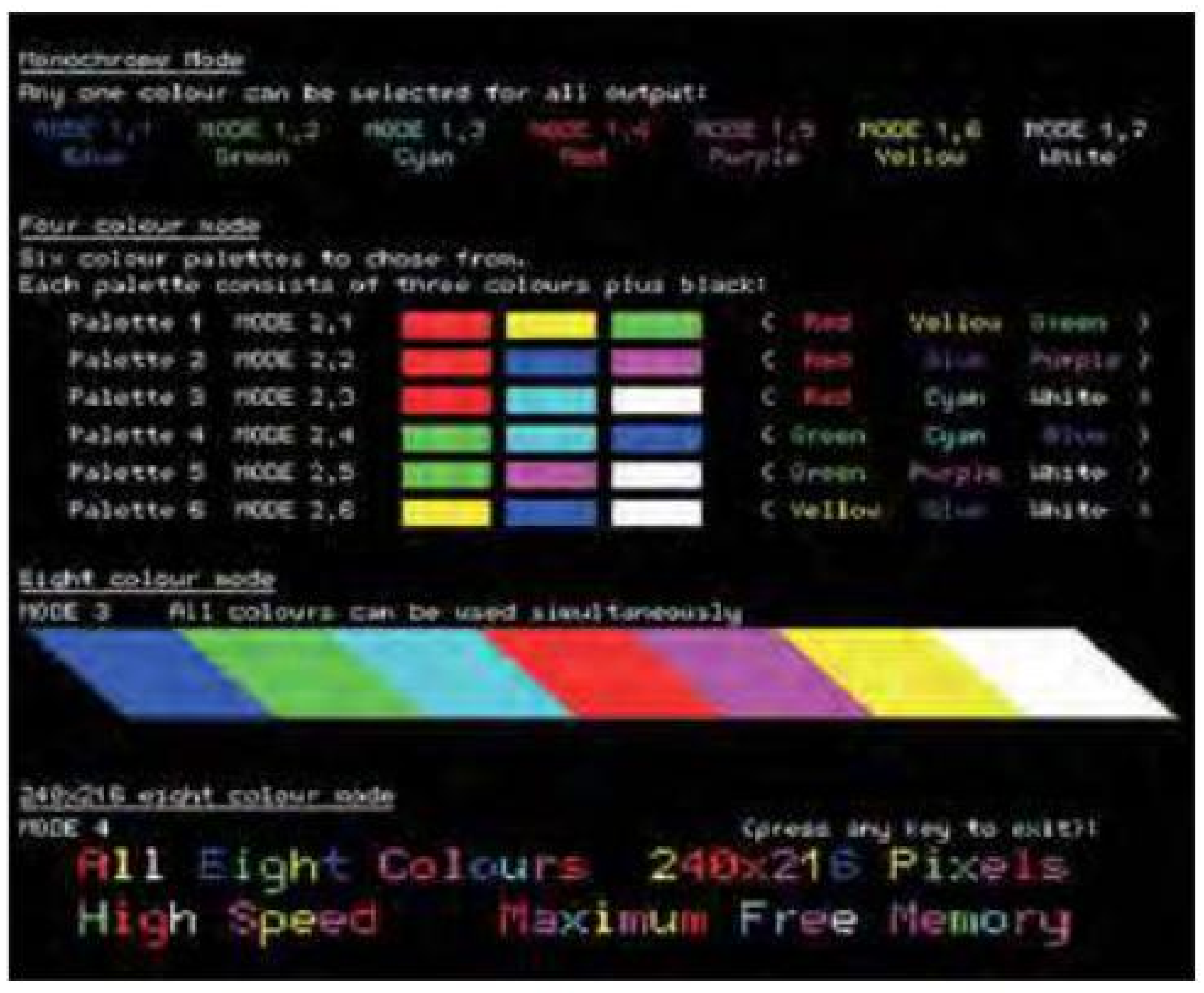
Graphics capabilities

We've already explored some of the easier graphics commands in the *User Manual*, but do have a play with the commands `CLS`, `PIXEL`, `LINE`, and `CIRCLE` directly from the command prompt (for starters, just try something as simple as `CLS RED`). There are many more graphical features that are available on the *Maximite*, so let's begin by working through four of the demo programs to see some of these features.



Graphics

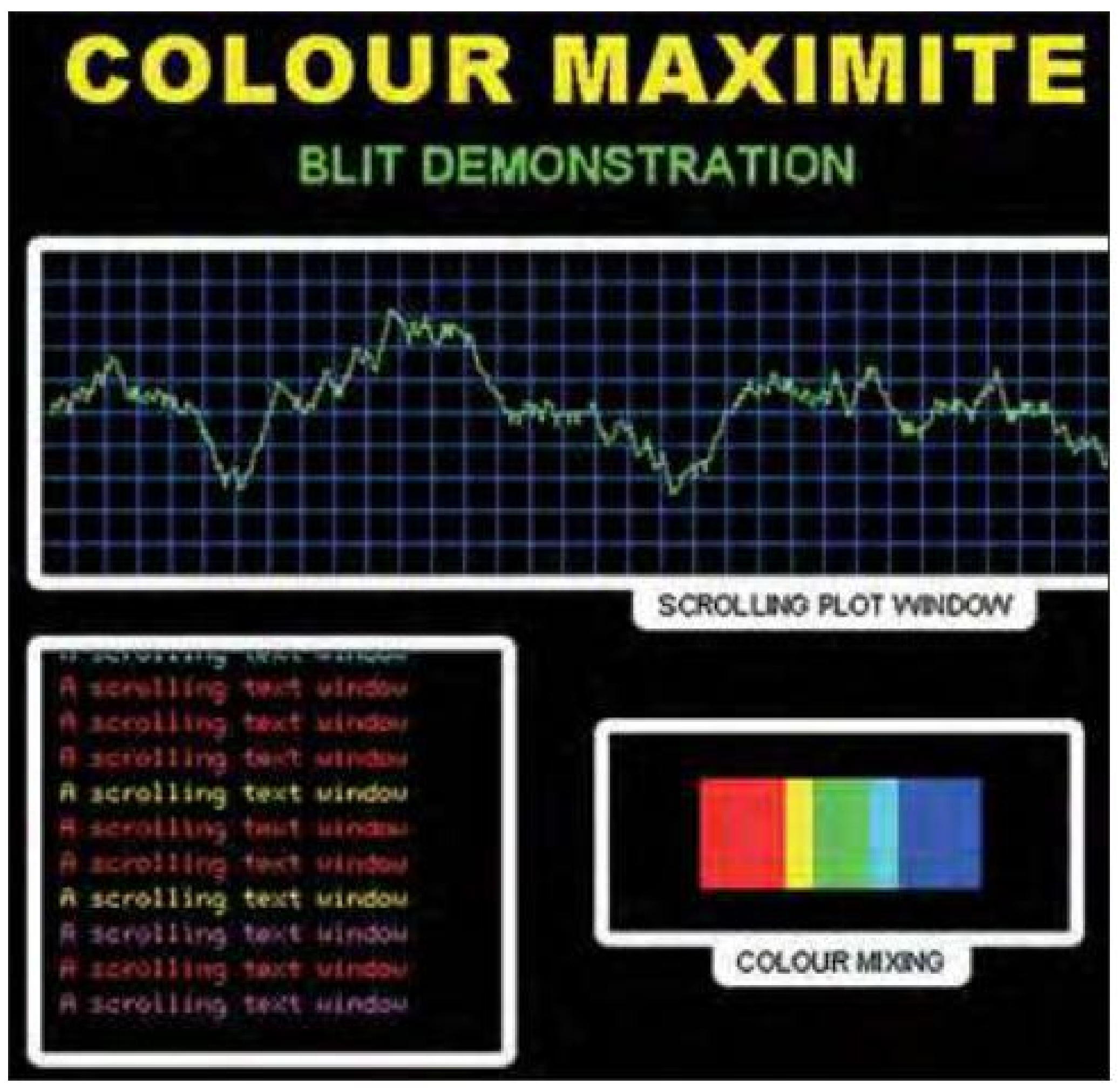
The `Graphics.bas` program is located in the root folder – run it with `RUN Graphics.BAS` (`Enter`). It demonstrates the speed of various *Maximite* graphics commands. It works through `PIXEL`, `LINE` and `CIRCLE` commands, and finishes with some nice animations using the `BLIT` command. Press any key to progress through the demonstration. As with all the programs, we recommend you look at the code to see how various commands are used.



```
Monochrome Mode
Any one colour can be selected for all output!
MODE 1,1  MODE 1,2  MODE 1,3  MODE 1,4  MODE 1,5  MODE 1,6  MODE 1,7
 Blue      Green     Cyan      Red       Purple    Yellow    White

Four colour mode
Six colour palettes to chose from.
Each palette consists of three colours plus black!
   Palette 1  MODE 2,1              ( Red     Yellow  Green  )
   Palette 2  MODE 2,2              ( Red     Blue    Purple )
   Palette 3  MODE 2,3              ( Red     Cyan    White  )
   Palette 4  MODE 2,4              ( Green   Cyan    Blue   )
   Palette 5  MODE 2,5              ( Green   Purple  White  )
   Palette 6  MODE 2,6              ( Yellow  Blue    White  )

Eight colour mode
MODE 3    All colours can be used simultaneously

240x216 eight colour mode
MODE 4                                   (press any key to exit)!
   All Eight Colours  240x216 Pixels
   High Speed         Maximum Free Memory
```

Modes

The `Modes.bas` program (in root) nicely demonstrates the four different screen modes available on the *Maximite* by showing them all simultaneously on one screen. The different modes allow you to balance speed, resolution, colour range and memory usage, as explained in the *User Manual*. For high-resolution (along with access to all eight colours), you would use `MODE 3`. For games, `MODE 4` is recommended as the bigger pixels are processed faster, meaning on-screen objects move quicker – examine the code to see how different elements are drawn. More importantly, play with the code to alter effects using the *User Manual* to guide you. (To be clear, we are referring to screen modes here – not the *Maximite's* three modes: Immediate, Editor, or Run.)



```
A scrolling text window
A scrolling text window
A scrolling text window
A scrolling text window
A scrolling text window
A scrolling text window
A scrolling text window
A scrolling text window
A scrolling text window
A scrolling text window
A scrolling text window
```

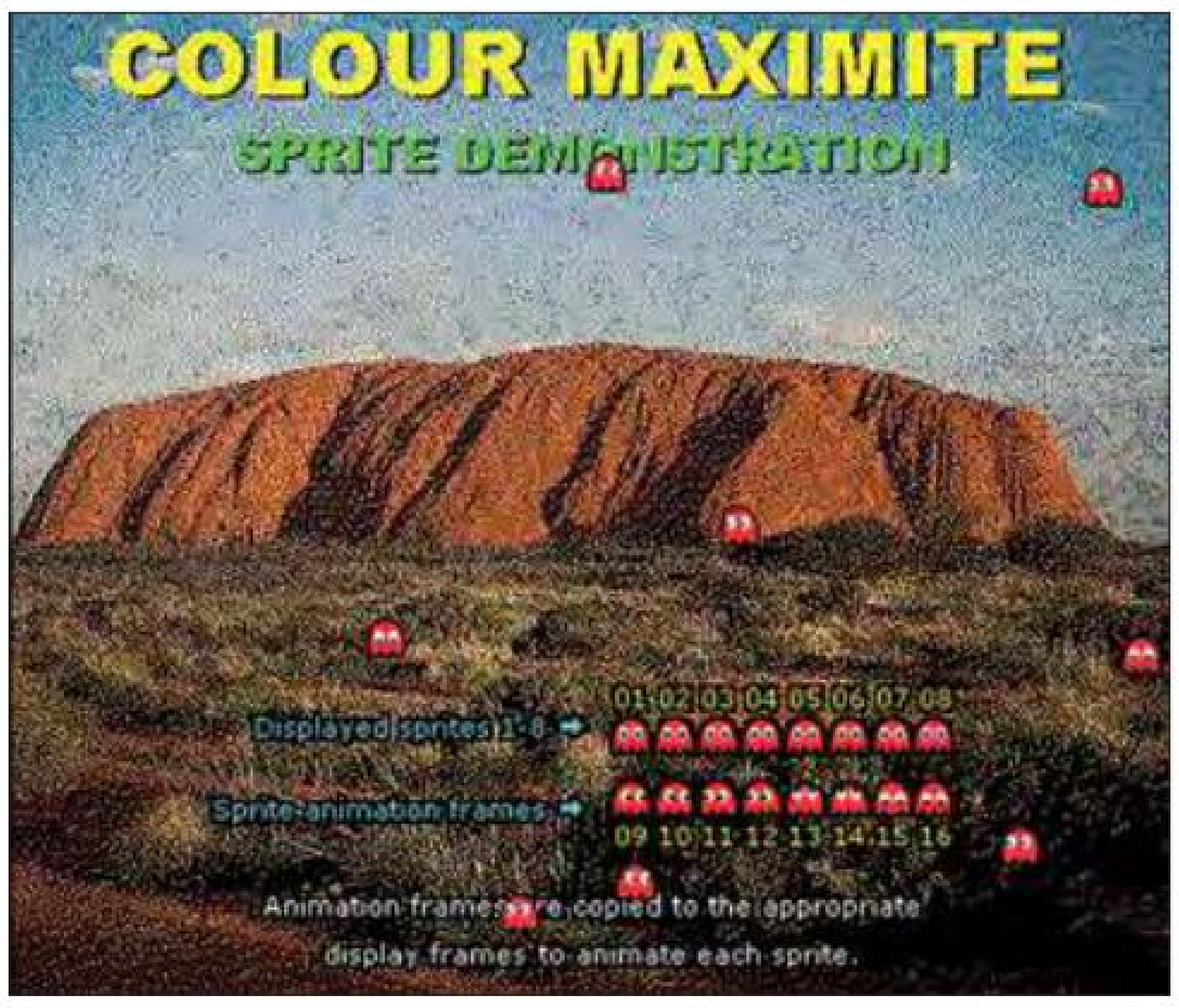
BlitDemo

`BlitDemo.bas` is a multi-file program, so first type `CHDIR BlitDemo` (`Enter`) and then `RUN BlitDemo` (`Enter`). To stop the program, press `Ctrl-C`. This will return you to the command prompt, with the SD card access still pointing to the *BlitDemo* folder (you can see this by typing `FILES` (`Enter`), after which you will see all the files that `BlitDemo.bas` uses). To return to the main folder on the SD card, type `CHDIR ..` (`Enter`). Typing `FILES` (`Enter`) will again show a list of all the demo programs / directories ready for you to try the next program. Follow this process for all multi-file demo programs.

BlitDemo shows how some fantastic animation effects can be generated by using the `BLIT` command. Check out the colour mixing in the lower right corner. Why not try changing the colour of the 'scrolling waveform' to ensure you understand how the `BLIT` command works. (This program runs in `MODE 3`.)

SprtDemo

This is another multi-file program. *SprtDemo* shows how sprites (blocks of pixels) can be drawn on the screen without affecting the background. In this demo, little 'Pacman ghosts' wander over a bitmap (`.bmp`) image of a well-known landscape. See if you can change the background to one of your own – hint: use something like Microsoft Paint to save a `.bmp` file with the appropriate pixel resolution and colour depth.



Animation frames are copied to the appropriate display frames to animate each sprite.

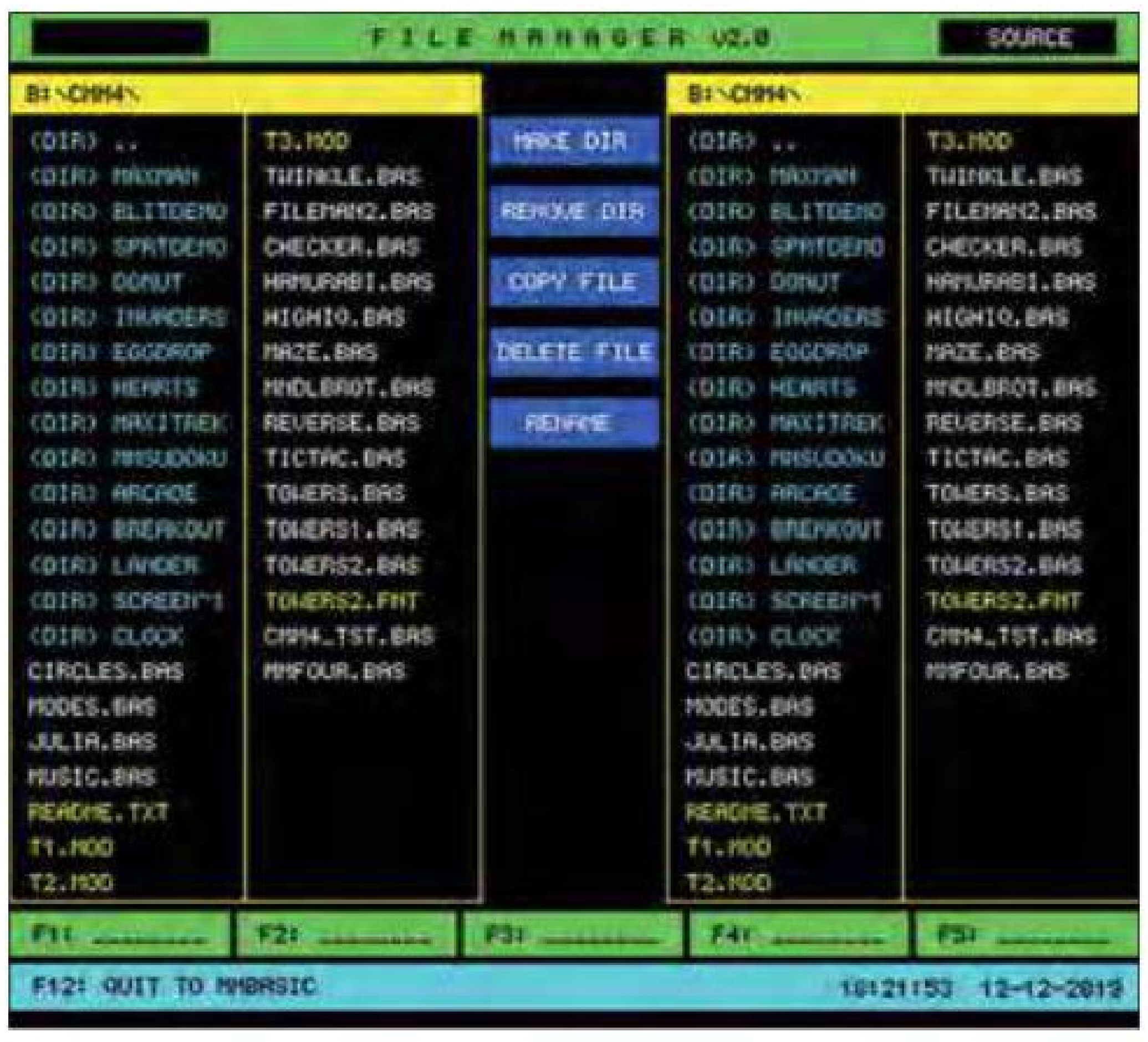
These four graphics demonstrations have shown you something new, and given you a chance to explore code and make changes. If you mess something up, simply re-copy the original program onto the SD card.

Further demo programs

Now take some time to try some of the other demo programs. One of the great things with MMBASIC is that it is easy to customise the code to suit your own requirements. Remember, all programs are written in BASIC – there is absolutely no machine code or complex C code! There are actually more programs in the download folder than shown here in the screenshots, so do be sure to try them all out. As you have just seen, some programs nicely demonstrate how to use the *Maximite's* graphical commands, while other programs provide some mind challenges; for example, *Tetris*, *Checkers*, and *Four-in-a-row*. Plus, there's a handful of action games, some that you can play straight away, and others requiring you to build a simple hardware controller (comprising a potentiometer and a button). Remember, the *Maximite* is easy to hook up to external hardware, and these particular games demonstrate the interaction between hardware and software in a fun way.

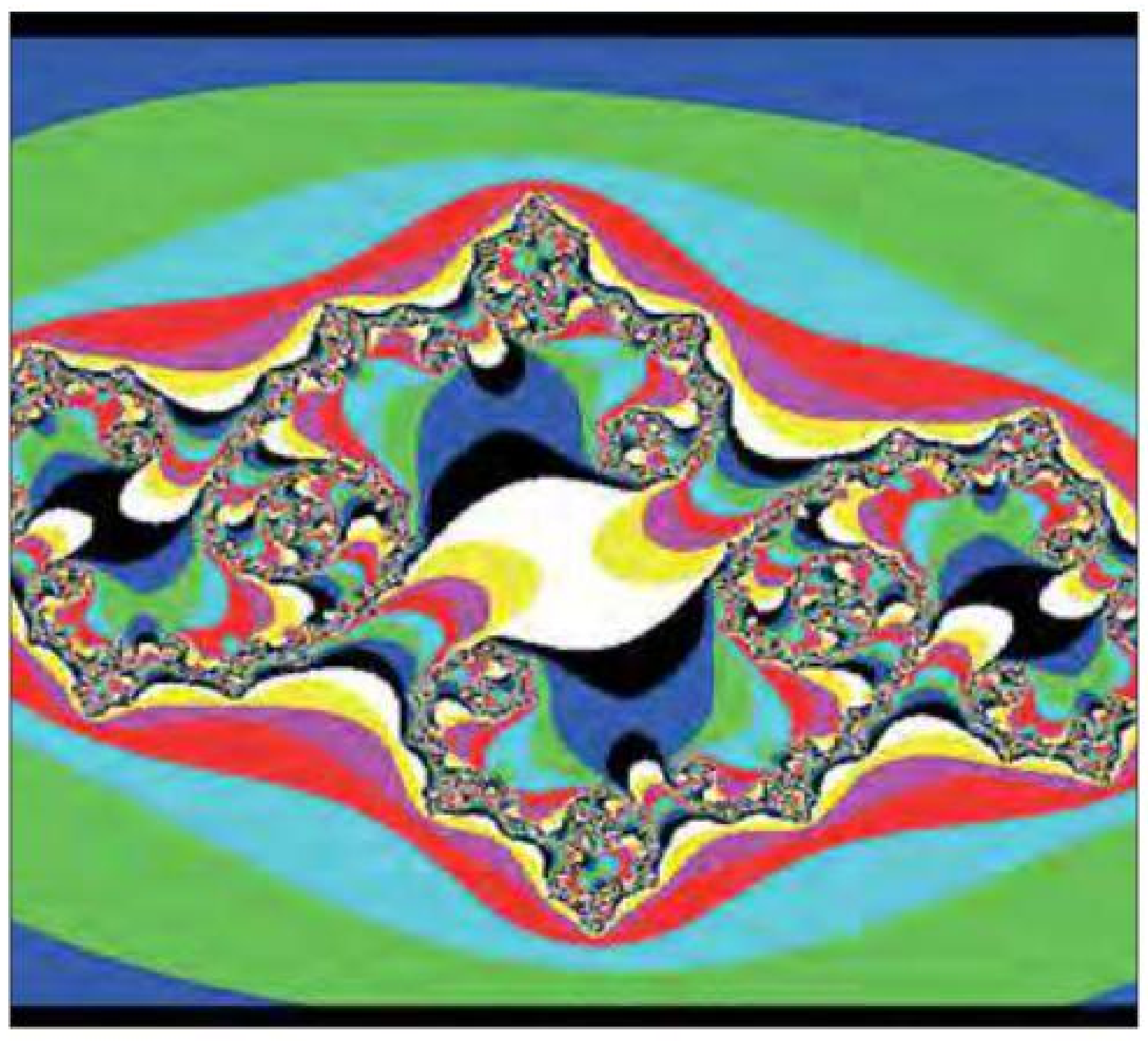
Important note: if a multi-file program uses any `.mod` sound files then you may have to perform a manual process before the program will run correctly – see next section!

All of the programs in the download folder have been collated from various authors around the world and we thank them all for making their code publically available. In some cases, the code has been written from scratch, specifically for the *Maximite*, whereas other programs are simply conversions of old BASIC code that was originally written for 80s home computers such as the BBC micro. If you look at the code, you will see that some incorporate line numbers. This raises an important point worth stressing – you can literally take any old BASIC program (with or without

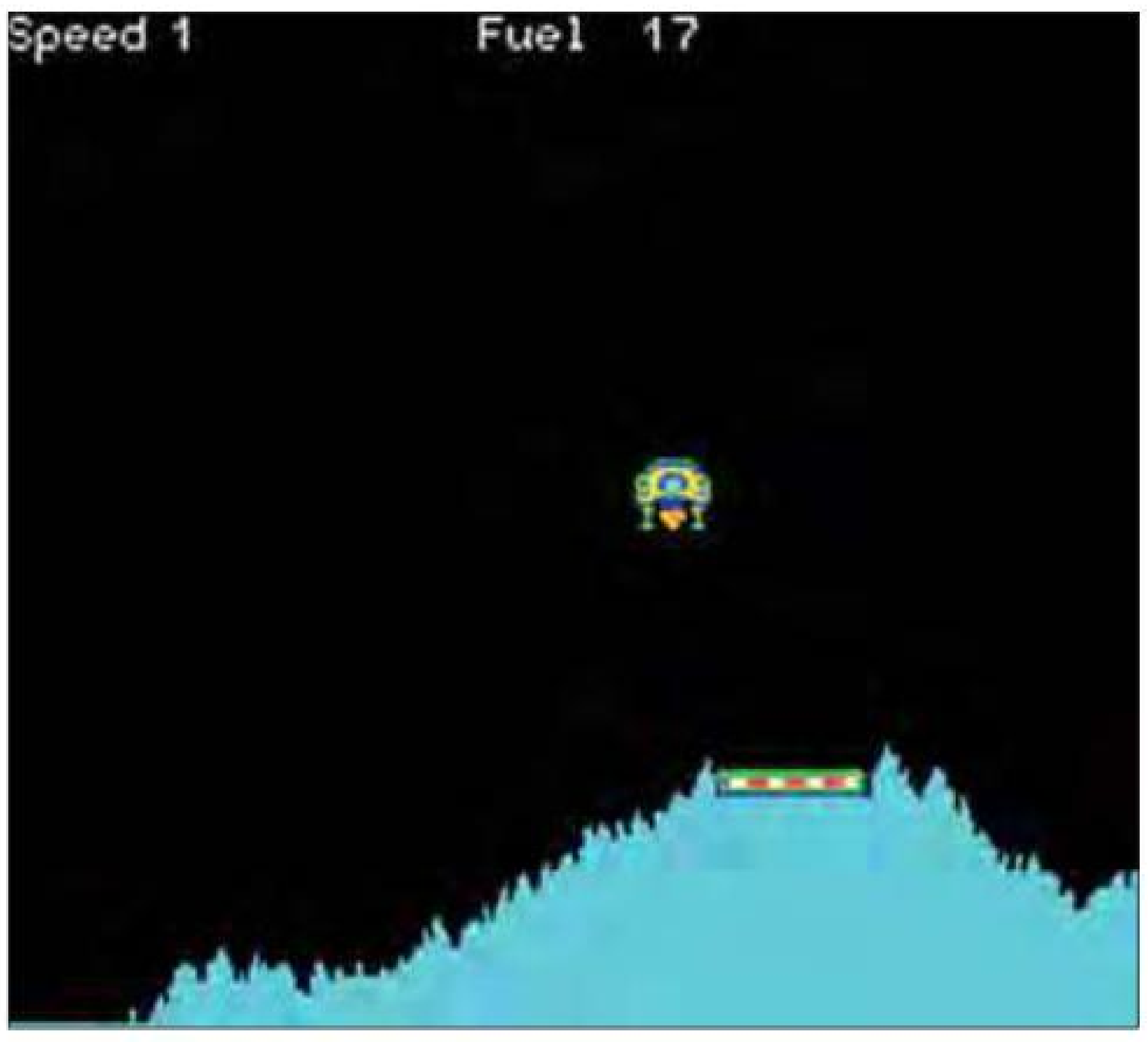


```
F I L E   M A N A G E R   V2.0                              SOURCE
B:\CMM4\                                  B:\CMM4\
<DIR> ..          T3.MOD       MAKE DIR     <DIR> ..          T3.MOD
<DIR> MAXMAN      TWINKLE.BAS  REMOVE DIR   <DIR> MAXMAN      TWINKLE.BAS
<DIR> BLITDEMO    FILEMAN2.BAS COPY FILE    <DIR> BLITDEMO    FILEMAN2.BAS
<DIR> SPRTDEMO    CHECKER.BAS  DELETE FILE  <DIR> SPRTDEMO    CHECKER.BAS
<DIR> DONUT       HAMURABI.BAS RENAME       <DIR> DONUT       HAMURABI.BAS
<DIR> INVADERS    HIGHIQ.BAS                <DIR> INVADERS    HIGHIQ.BAS
<DIR> EGGDROP     MAZE.BAS                  <DIR> EGGDROP     MAZE.BAS
<DIR> HEARTS      MNDLBROT.BAS              <DIR> HEARTS      MNDLBROT.BAS
<DIR> MAXITREK    REVERSE.BAS               <DIR> MAXITREK    REVERSE.BAS
<DIR> MMSUDOKU    TICTAC.BAS                <DIR> MMSUDOKU    TICTAC.BAS
<DIR> ARCADE      TOWERS.BAS                <DIR> ARCADE      TOWERS.BAS
<DIR> BREAKOUT    TOWERS1.BAS               <DIR> BREAKOUT    TOWERS1.BAS
<DIR> LANDER      TOWERS2.BAS               <DIR> LANDER      TOWERS2.BAS
<DIR> SCREEN~1    TOWERS2.FNT               <DIR> SCREEN~1    TOWERS2.FNT
<DIR> CLOCK       CMM4_TST.BAS              <DIR> CLOCK       CMM4_TST.BAS
CIRCLES.BAS       MMFOUR.BAS                CIRCLES.BAS       MMFOUR.BAS
MODES.BAS                                   MODES.BAS
JULIA.BAS                                   JULIA.BAS
MUSIC.BAS                                   MUSIC.BAS
README.TXT                                  README.TXT
T1.MOD                                      T1.MOD
T2.MOD                                      T2.MOD
F1: _______  F2: _______  F3: _______  F4: _______  F5: _______
F12: QUIT TO MMBASIC                                10:21:53  12-12-2019
```

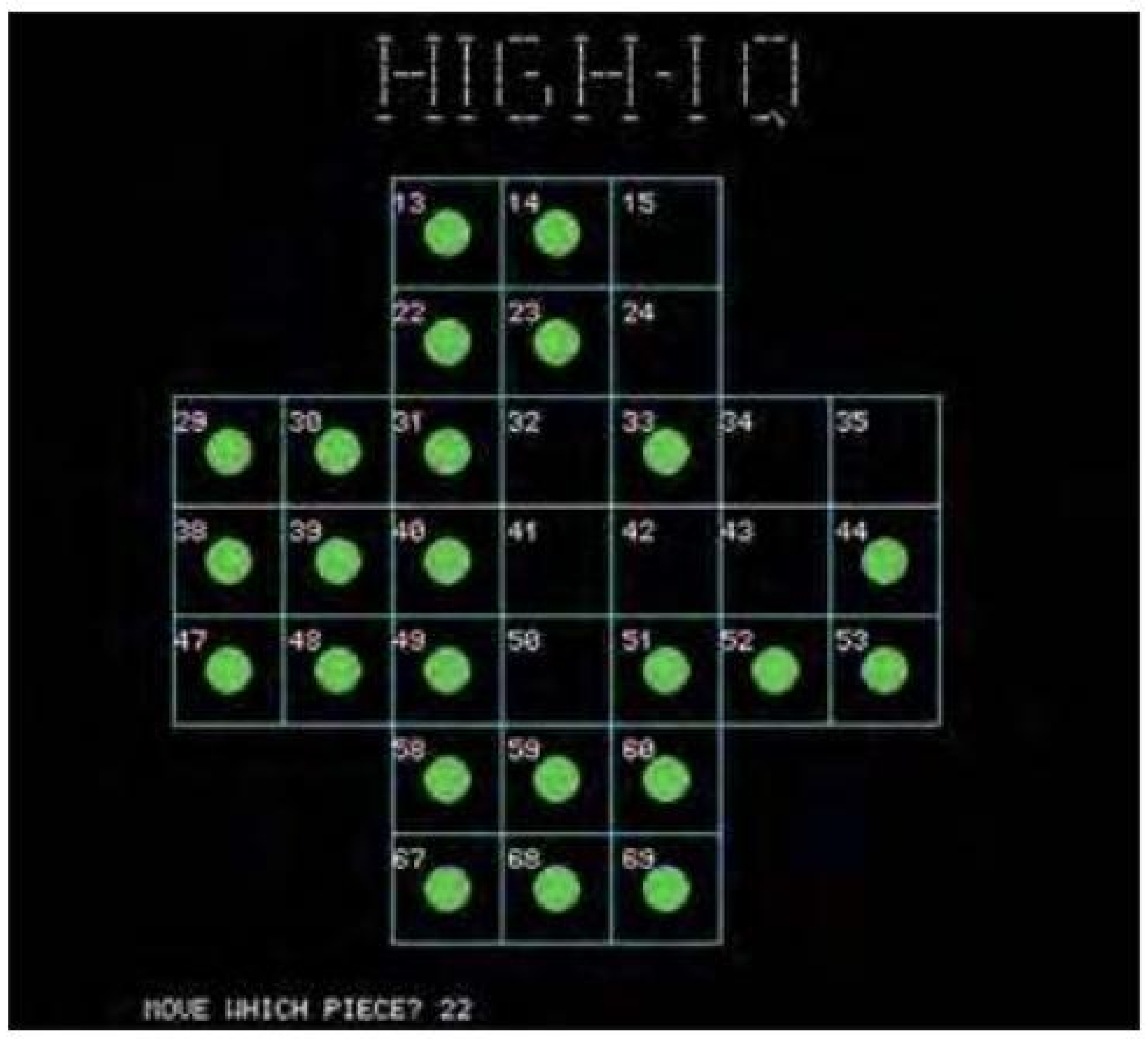
FileMngr.bas – A simple file explorer utility. You use the arrow keys to navigate to a .bas program file (or a folder), and then press Enter to launch the program (or open a folder).



Julia.bas – Generates a colourful image that is mathematically similar to the famous Mandelbrot set. Be patient, it takes about 15 minutes to completely generate the image.

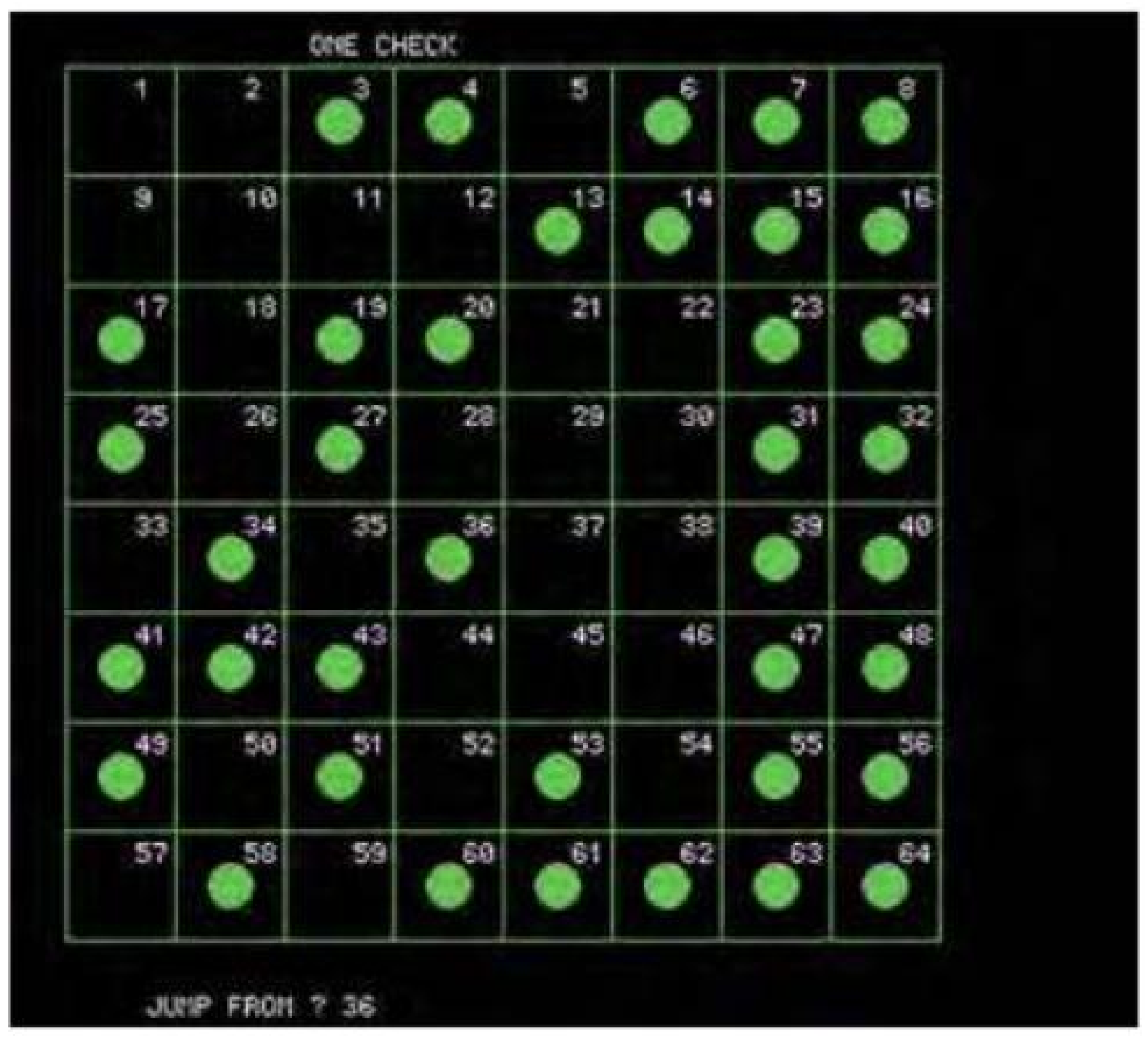


MoonLand.bas – Use the arrow keys to land your spacecraft on the landing pad. Ensure you land as gently as possible by minimising the speed. (Multi-file program – manually copy .mod files).



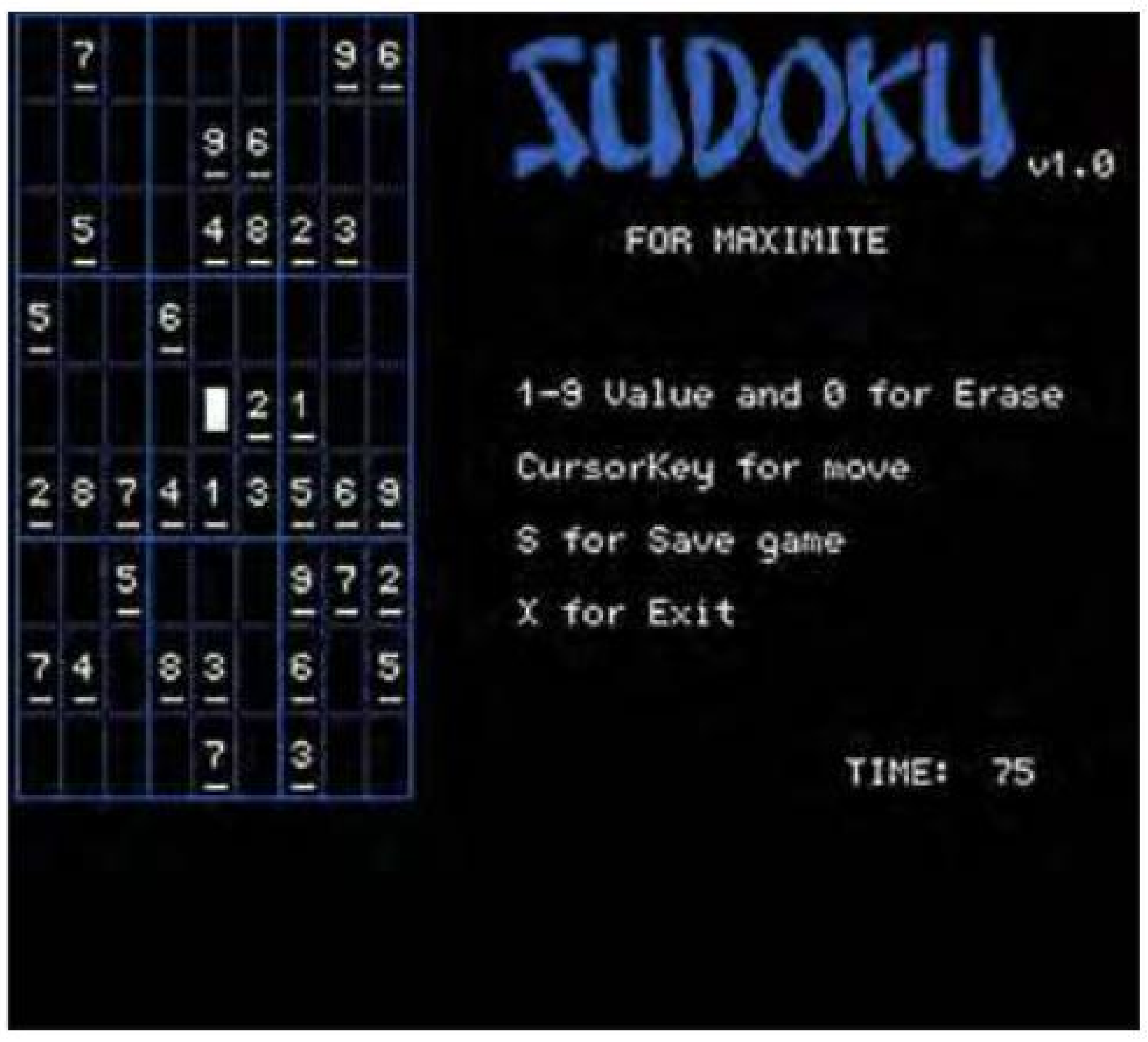
```
MOVE WHICH PIECE? 22
```

HighIQ.bas – This version of the classic *Solitaire* game challenges you to remove all but one of the 32 counters. You can jump either horizontally or vertically by entering the grid reference numbers.



```
ONE CHECK
JUMP FROM ? 36
```

Checkers.bas – This is another variation of solitaire, and is similar to HighIQ. However, in this version you can only jump in a diagonal direction, and there are more counters to remove.



```
FOR MAXIMITE

1-9 Value and 0 for Erase
CursorKey for move
S for Save game
X for Exit

TIME:  75
```

Sudoku.bas – Challenge yourself to this popular number puzzle. Try to populate the empty squares with digits 1-9 so that no digit is repeated in a row, column, or 3×3 cell. Three difficulty levels await.

line numbers), and migrate the code to MMBASIC without too much effort.

.mod sound files

Playback of a `.mod` sound file results in very impressive sound, as witnessed back in *Part 2* when you tested your *Maximite* with the `MUSIC` demo. However, for the *Maximite* to be able to perform this task in the background, the data in a `.mod` sound file needs to be accessed very quickly by the PIC processor. Reading the `.mod` data directly from the `.mod` file on the SD card is just too slow, hence the `.mod` file needs to reside in (ie, copied to) the PIC's ultra-fast memory. However, the amount of ultra-fast memory available is very limited, so if there are any existing `.mod` files from a previous program, then these files need to be deleted from the fast memory first to make space for new sound files. Otherwise, you will likely see an 'out of memory' message.

The memory space where `.mod` files need to be placed is referred to as 'Drive A'. To access this, type `DRIVE A` (`Enter`) and then type `FILES` (`Enter`) to see if any files are currently there. Note that the number of files, and the number of 'bytes free' are displayed. For completeness, Drive B is the only other 'drive' on the *Maximite*, and this refers to the SD card itself. Drive B is the default drive when the *Maximite* is powered on (or reset).

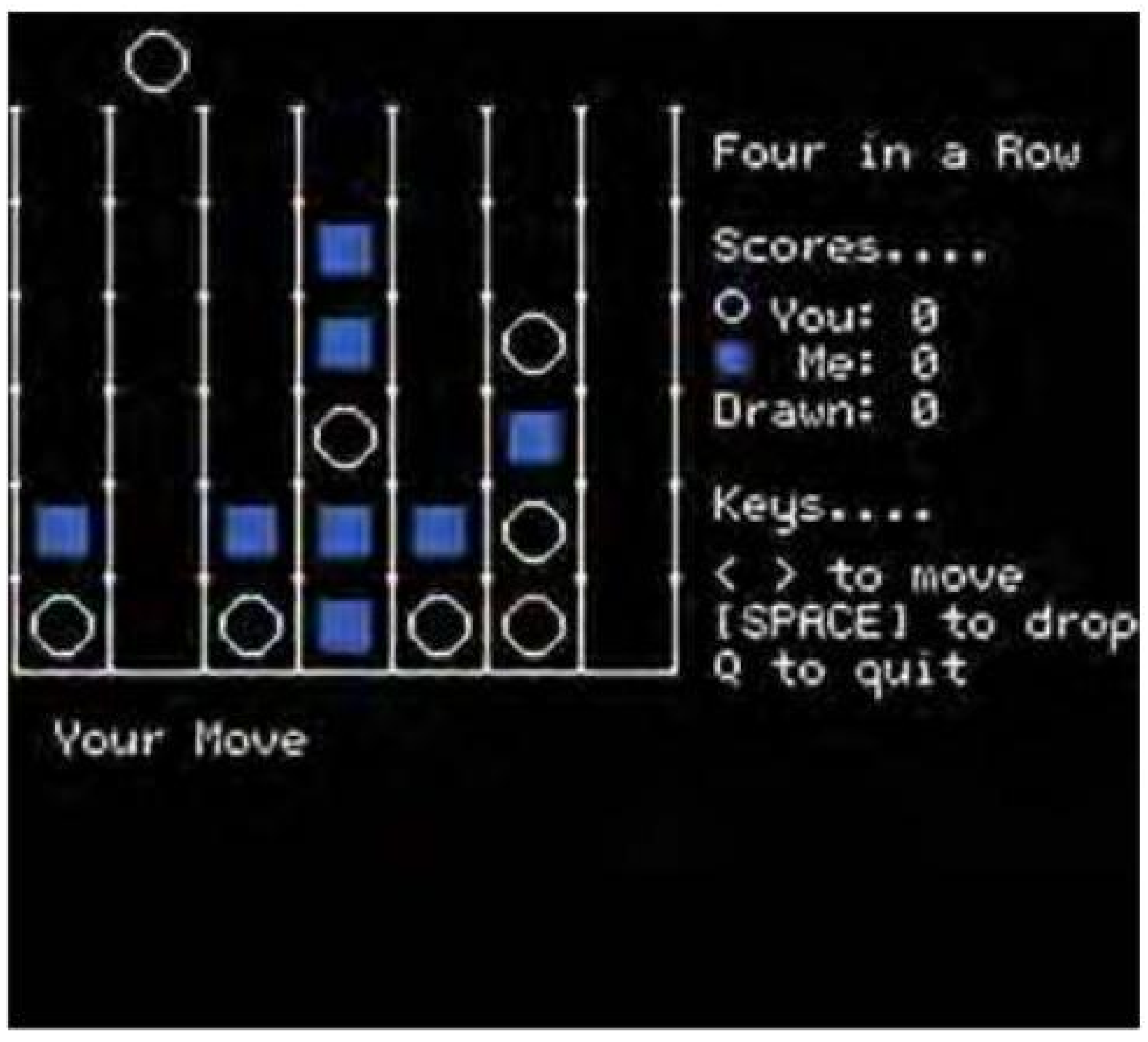
Deleting .mod files

To delete a file from Drive A, use the `KILL "filename"` command (this causes the screen to blank temporarily). To gain the maximum possible space in Drive A for new files, the `KILL` command should ideally be repeated to delete each file until there are none left. You can check how many files are left by typing `FILES` (`Enter`) at any time. If you have been following this project, and if you successfully ran the `MUSIC` demo, then you will likely see `T1.mod`, `T2.mod`, and `T3.mod` listed. You should now delete these files to free up space. When no files are left, type `DRIVE B` to point back to the SD card (and then type `FILES` (`Enter`) to list the files and folders (`<DIR>`) stored on the SD card).

Installing .mod files

Once we have space in Drive A for new `.mod` files, we now potentially need to copy the files from the SD card to Drive A. 'Potentially', because some programs will actually do this automatically for you (in code). The `MUSIC` demo program is a good example of this (it automatically copied `T1.mod`, `T2.mod`, and `T3.mod` into Drive A). However, other programs require you to copy the files manually. To understand if you need to copy the files yourself, just run the program, and see if an error message like 'PlayMOD Error: Cannot find file' appears – if so, you will need to do transfers manually. We will now work through the process involved by using the *MoonLand* demo program (which has three `.mod` files that need copying to Drive A).

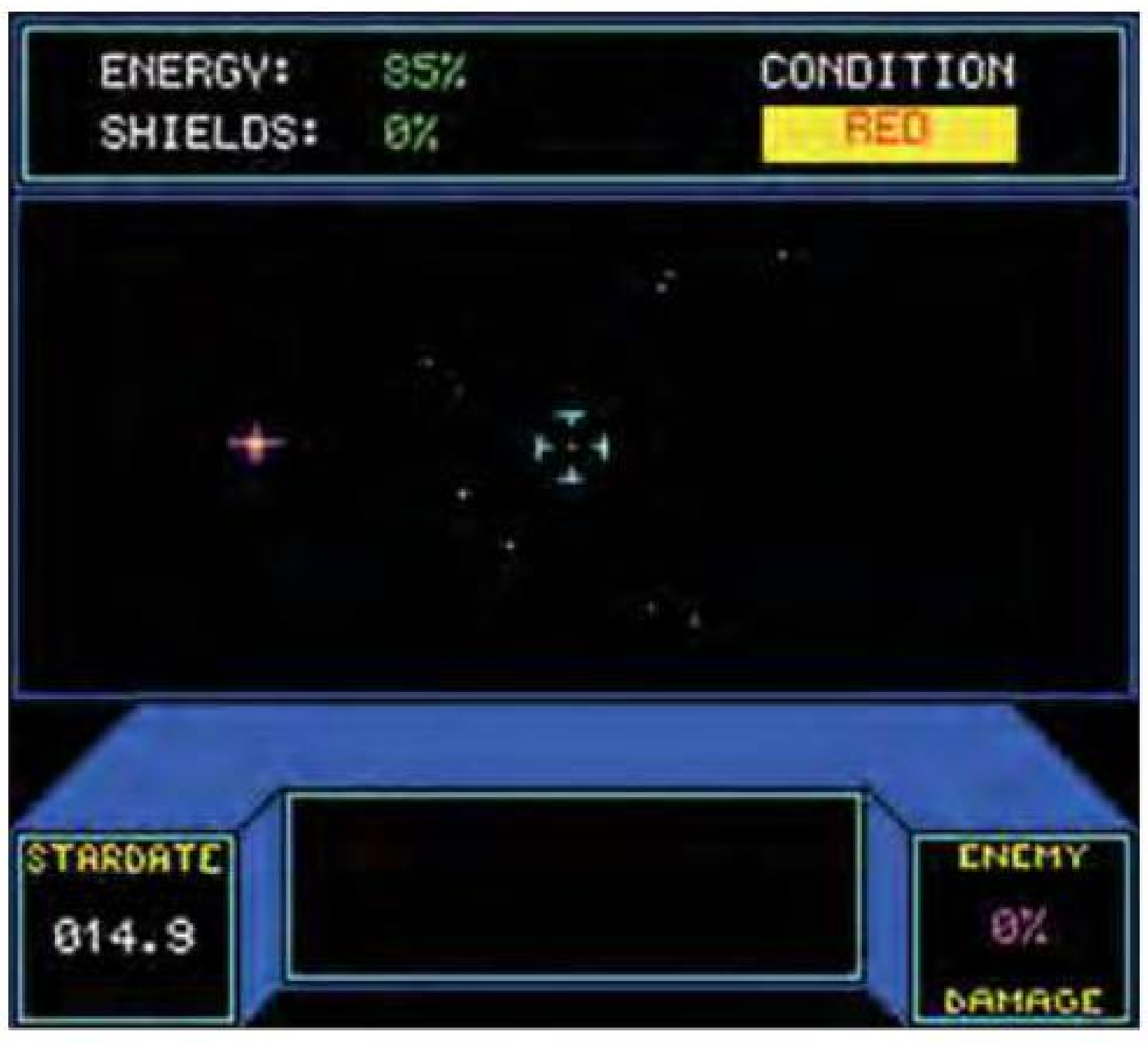
Begin by pointing to the *MoonLand* folder by typing `CHDIR MoonLand` (`Enter`), and then list the `.mod` files with `FILES` (`Enter`). Before we go any further, lets see the error message generated when the `.mod` files are missing from Drive A. Type `RUN MoonLand` (`Enter`), and press any key to start the game (you will then see a screen similar to the above screenshot). Press the UP arrow key and you will see an error message as the program is trying to play the 'missing' `turbine.mod` sound file. You will see large characters on the screen – so type `MODE 3` (`Enter`) to return to normal size characters (ignoring any error message). Now type `FILES` (`Enter`) and you will



FourRow.bas – The classic four-in-a-row program; in this version you play against the *Maximite*. Use the < and > keys to select a column, and then drop your counter by pressing the spacebar.

Welcome to the incredible
MaxiTrek
3D

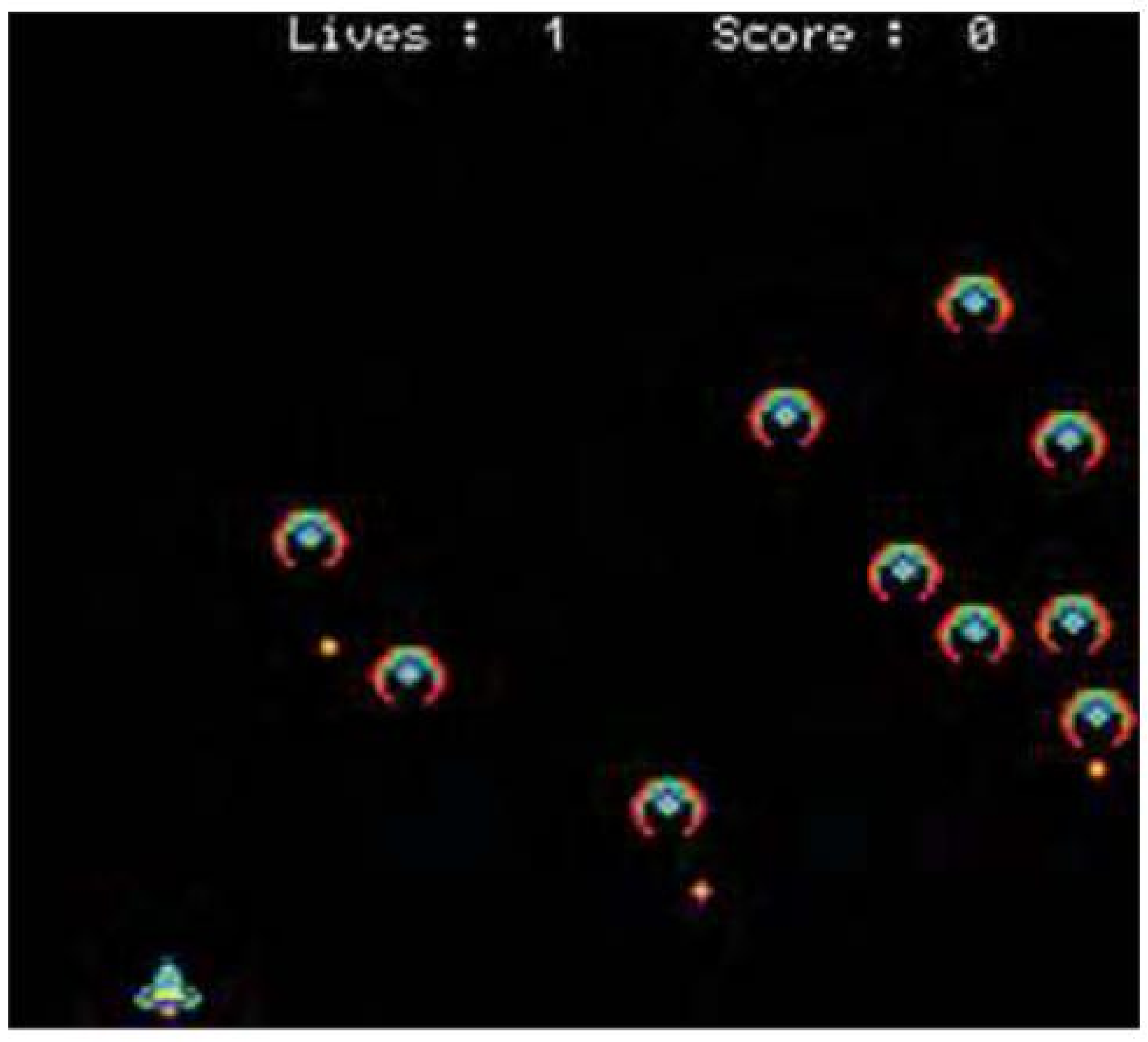
MaxiTrek.bas – A retro game in which you travel the galaxy. You mission is to destroy the fleet of Arduitrons that have attacked your planet. Press I to see the keyboard controls.



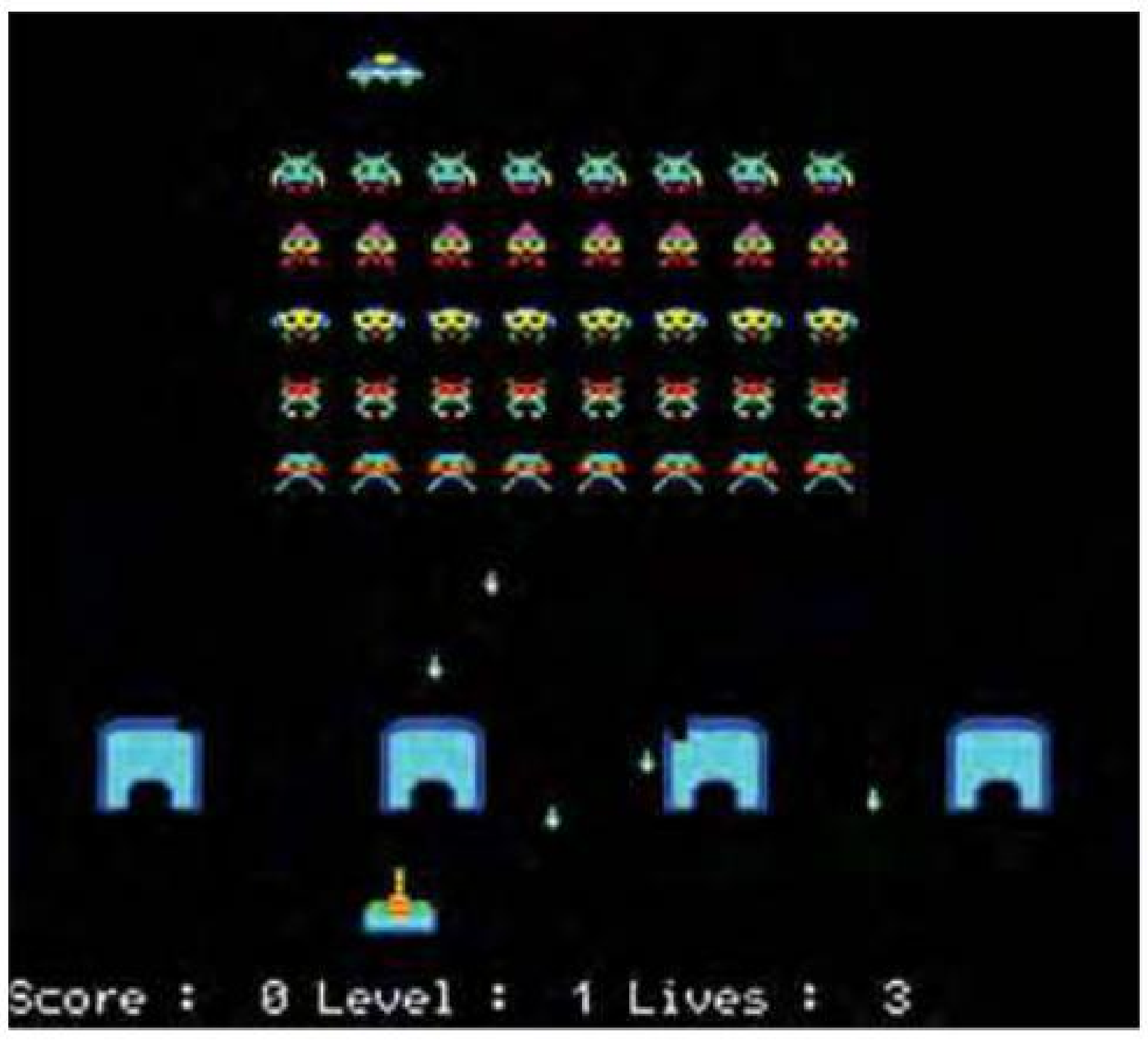
MaxiTrek – Pressing M displays a map of the galaxy. Navigate to different parts in order to attack the enemy. (The code automatically copies the .mod file into Drive A (and renames it title.mod)).

COLOUR
MAXIMITE
20

Breakout.bas – This game is a variation of the classic breakout game but with a difference – you need to build a game controller! Details are provided at the start of the program code.



Arcade.bas – An arcade-style game in which you need to shoot the enemy. Requires a DIY controller (potentiometer and button – see start of code for details). (Copy the two .mod files to Drive A).



Invaders.bas – A copy of the classic Space Invaders game. This also requires the DIY controller (potentiometer and button – see start of code for details). (Copy the two .mod files to Drive A).

see that the *Maximite* is pointing to Drive A (probably containing 0 files) – this is because the program crashed while trying to locate the `turbine.mod` file which needs to be in Drive A.

So point the *Maximite* back to Drive B with `DRIVE B` (`Enter`), and then type `FILES` to list the files in the *MoonLand* folder. Next, use the `COPY "source" TO "destination"` command on each `.mod` file. Start with `COPY "explode.mod" TO "A:explode.mod"` (`Enter`). (The screen will go blank temporarily while the file is copied.) Copy the other two files with `COPY "landed.mod" TO "A:landed.mod"` (`Enter`) and `COPY "turbine.mod" TO "A:turbine.mod"` (`Enter`). Use `KILL` to delete any misspelt file names. When all three `.mod` files have been copied into Drive A correctly, type `DRIVE B` (`Enter`) to point back to the SD card. You can now type `RUN MoonLand` to play the game and this time you will not see the error message).

Note: After running a multi-file program, ensure that you're pointing to Drive B (SD card) and not Drive A (fast *Maximite* memory). To do this, use the command `DRIVE B` (`Enter`). Then use `CHDIR ..` to go up a level to see all the other demo programs, and folders (`<DIR>`) in the root folder.

The above topic has been discussed in detail since several of the demo programs use `.mod` sound files and the program won't run properly if there is not enough space in Drive A for the `.mod` files. In summary, there are possibly two tasks that need to be performed – clear space in Drive A, then (potentially) copy the `.mod` file(s) manually into Drive A. Once you have done this a couple of times, it will become second nature!

Now it's time for you to explore the other demo programs. Remember, there are more programs contained on the SD card than are shown here as screenshots.

GPIO hardware control

As we have often said, it is very easy to interface external hardware with the *Colour Maximite Computer*. The *User Manual* provides various examples on the commands used (especially `SETPIN` and `PIN`) so we won't repeat that information here. Instead, we will explain how you address the 40 available I/O pins (20 external on the rear-panel connector, and 20 internal on an Arduino footprint connectors). We will end the *Colour Maximite Computer* project with an example of software controlling some externally connected hardware. The example is based on the Blinkt! RGB LED module featured in this month's *Make it with Micromite* (*MIWM*), and we'll use the `SPI` command to control eight ultra-bright RGB LEDs.

Before we start, please refer to Fig.2 in *MIWM Part 2* (*PE*, December 2019) to see how to build a simple logic probe comprising an LED, 470Ω resistor, and some jumper leads. Next, assemble this simple (and useful) test device. You can check it works correctly by inserting the test probe onto either 5V or 3.3V (and the LEDs cathode to GND) – if the LED lights then all is good. If the LED does not light up, then first check the LEDs polarity, and also check the resistor is the correct value (or between 270Ω and 1kΩ).

The rear-panel connector

At the back of the *Colour Maximite Computer*, there is a centrally mounted 26-way connector. This connector makes 20 GPIO pins available, along with GND, 3.3V and 5V power outputs. The pinout is shown in Fig.1

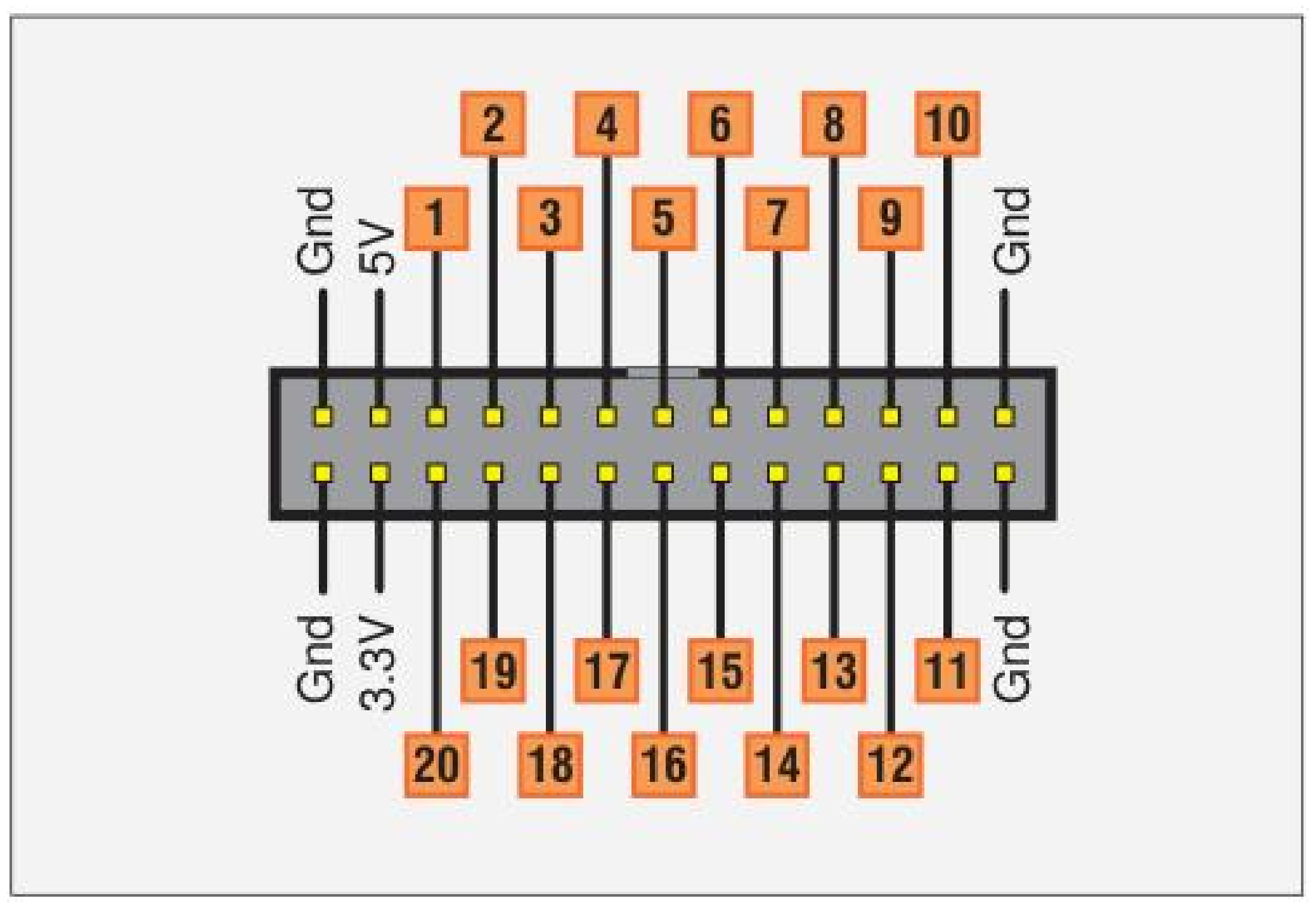


Fig.1. The pinout for the 26-way connector on the rear panel (as viewed outside box). It provides 20 GPIO pins (numbered 1 to 20) and also 3.3V and 5V power for powering external hardware.

(as viewed when looking at the rear panel). The numbers in orange boxes are the pin numbers that are used to reference these twenty GPIO pins. If we connect the LED test probe to Pin 1 (the third pin along from top left) and the other end to GND, then to be able to control the LED with software, we would first need to configure Pin 1 as a digital output (`DOUT`) by using the command `SETPIN(1),DOUT`. Then, to turn the test LED on (set Pin 1 to a high logic level), you would use `PIN(1)=1`. Likewise, to turn it off, use `PIN(1)=0`. Use the test probe to confirm this works as expected.

The Arduino connector

Inside the case, you will see two 6-way, and two 8-way sockets that make up the Arduino footprint connector. Alongside each socket you will see the Arduino pin references highlighted on the silkscreen. This is shown in Fig.2, along with the pin numbers that are used to reference these twenty GPIO pins. If we were to connect the test probe to the lower left socket (marked `D0`), then in order to use software to control the LED we would first configure pin `D0` (pin 21) as a digital output with `SETPIN(21),DOUT`. Note that with the Arduino pins we can also reference the pins by the silkscreen legend – so `SETPIN(D0),DOUT` will perform exactly the same result. Then to turn the LED on, simply use either `PIN(21)=1` or `PIN(D0)=1`. Likewise, to turn it off, use either `PIN(21)=0` or `PIN(D0)=0`. Once again, go ahead and check that both these pin references work as expected to control the test LED.

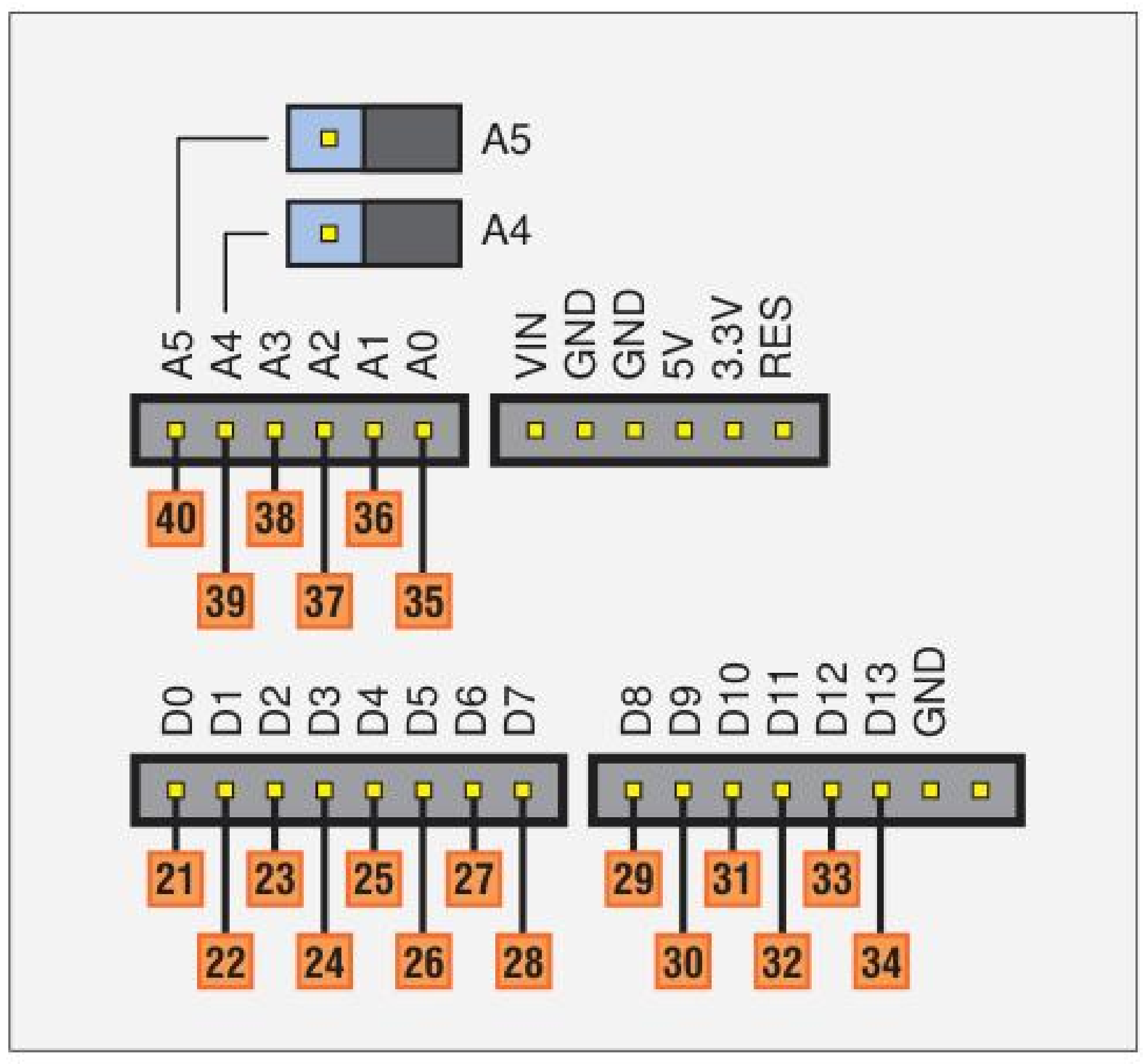


Fig.2. The pinout for the 20 GPIO pins available on the internal Arduino connector. These pins are numbered 21 to 40, and can also be referenced by the 'Arduino name' (D0-D13, A0-A5).

Now that we know how to address the 40 available GPIO pins (and where they are physically located), we next need to explain that some pins perform specific or special tasks. These pins (and their functions) are:

Pin 12 = I^{2}C Data (SDA) and IR receiver
Pin 13 = I^{2}C Clock (SCL)
Pin 15 = COM1 Rx
Pin 16 = COM1 Tx
Pin 17 = COM1 RTS
Pin 18 = COM1 CTS
Pin D0/21 = COM2 Rx
Pin D1/22 = COM2 Tx

SPI and one-wire can use any digital I/O pin – the pin numbers are specified in the relevant MMBASIC command (as commented in the SPI example below).

We recommend you work through some of the examples in the *User Manual* to get used to how to control hardware. And for readers following the *Make it with Micromite* (*MIWM*) series: a lot of the topics and projects covered in that series can be migrated to the *Colour Maximite Computer* with minimal change. However, there are two important points that need to be highlighted:

1. The *Colour Maximite Computer* is based on a 100-pin PIC micro-controller, whereas the Micromite is based on a 28-pin PIC. Therefore, the pin numbers quoted in the *MIWM* series will not apply to the *Maximite*. Instead, any external hardware will need to be connected to the appropriate *Maximite* pins. The *MIWM* code then simply needs to be updated (to reflect the new pin numbers) before it will run properly on the *Maximite*. This is much easier than it sounds.
2. MMBASIC can only connect to a single display. Since the *Maximite* has a dedicated VGA monitor for its 'display', no other external display can be added. Therefore, any program code for *MIWM* projects that incorporate the IPS display (or any other display) will need to be modified to write and draw to the VGA monitor instead. This will generally mean having to use different commands and/or parameters for the graphical commands.

Have a look at the *MIWM* series and convert some of the projects to run on your *Maximite*. To help you get started, let's modify parts of the *Mood Light* from this month's article and control the RGB LEDs from the *Maximite*.

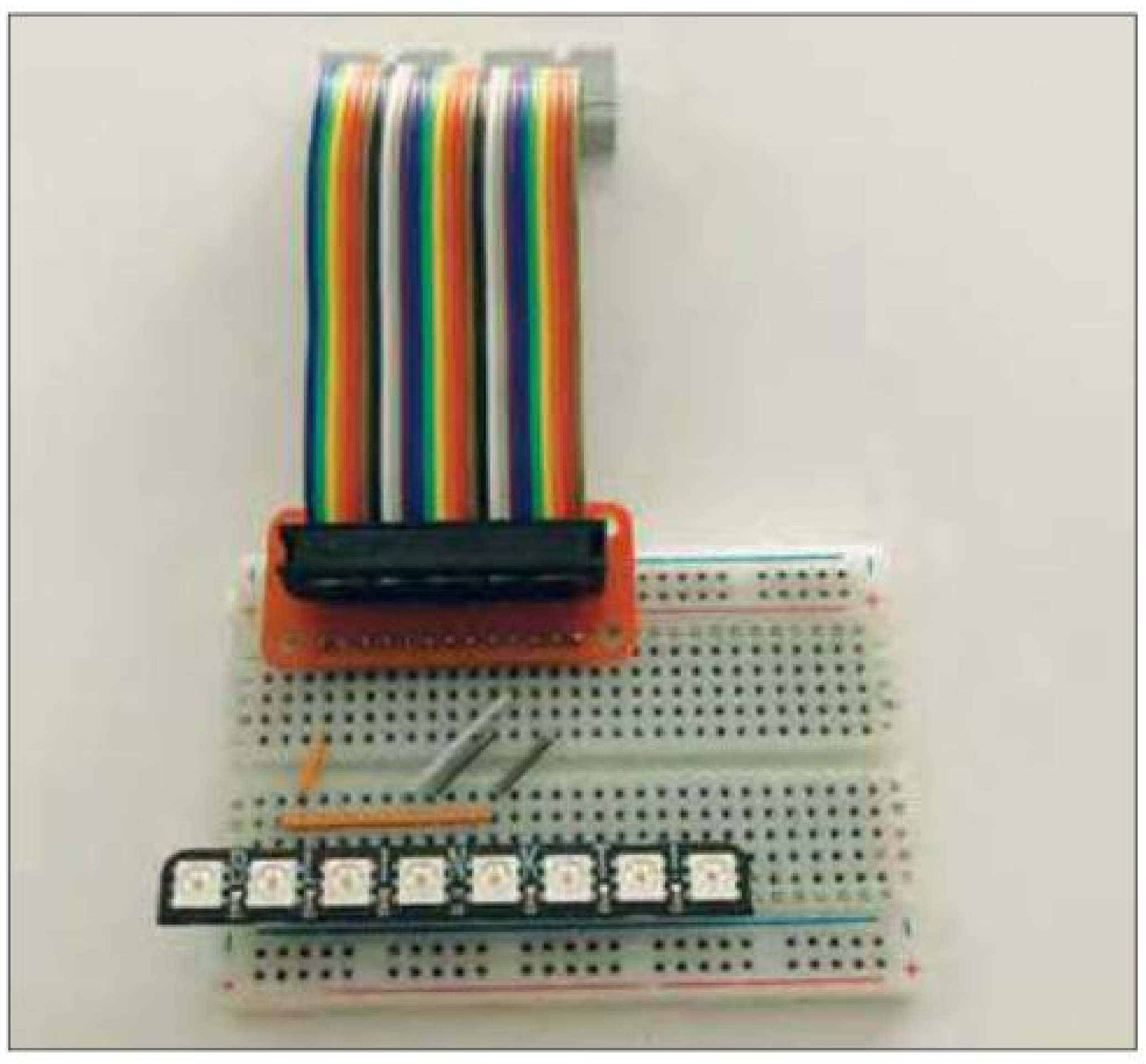


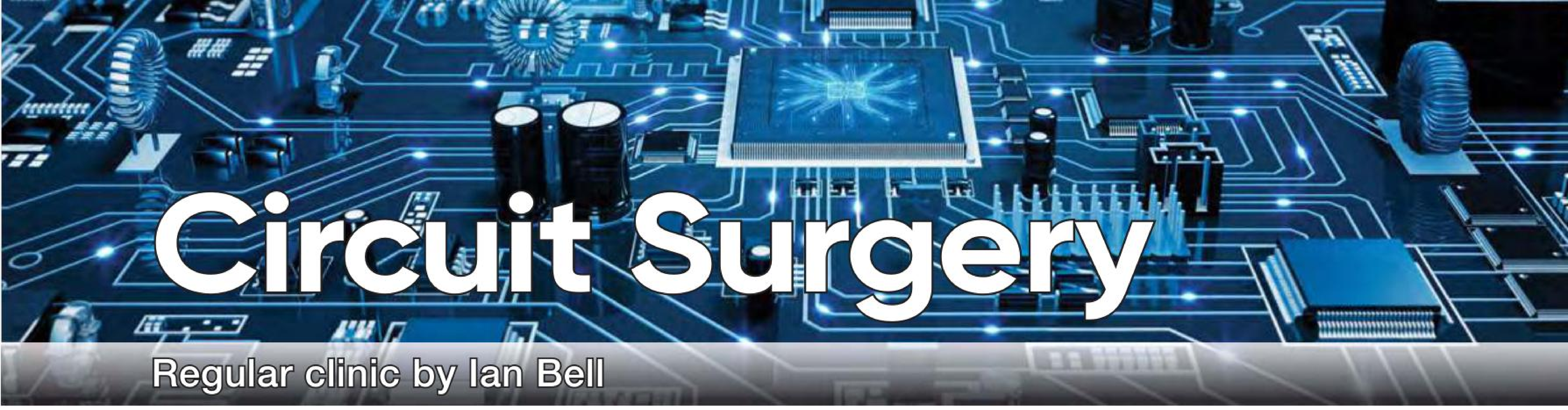
Fig.3. The *Maximite Mood Light* is built around the Blinkt! module (see page 67) and is connected to the rear-panel connector via a short ribbon cable. A suitable adaptor board keeps everything tidy.

Maximite Mood Light!

Here's a practical example, explaining how to connect a Blinkt! module to the *Maximite* and control it with a small program. We won't repeat the Blinkt! operational details other than to say that we need four connections – 0V, 5V, SPI Data, and SPI Clock. Do read this months *MIWM* article to understand the SPI data that we need to send to the Blinkt! to control LED brightness and colour. We can connect the Blinkt! to the *Maximite's* rear-mounted connector by using a short ribbon cable, and a breadboard to keep everything tidy. To make it easier to connect hardware to the rear-mounted connector, we recommend the use of a T-Cobbler module. The T-Cobbler simply allows a ribbon cable to be plugged into a breadboard. An alternative to the T-cobbler is something like that shown in Fig.3.

The four pins we need to connect to on the Blinkt! are shown in *MIMW*, Fig.4, page 67. At the *Maximite* end, the positions of 0V and 5V on the rear-panel connector are shown in Fig.1. SPI Data and SPI Clock can be connected to any available I/O pin (the selection is specified in the SPI command). Here, we have chosen to use pins 2 and 3 respectively.

Once these four connection have been made, we need to send 41 bytes of data to set a colour on the eight RGB LEDs (see Fig.6 on Page 67). We have written a very short program to do this – **MoodLite.bas**. Download and run it, follow the on-screen instructions and you should soon see some action on the LEDs. We will not explain the code in detail here – comments are scattered throughout the program. Try adding new features such as controlling colour with an IR remote control. A good exercise is to make the *MIWM Mood Light* software fully operational on the *Maximite*. This is not as daunting as it sounds, and as usual, if you need help, just drop me an email!



Circuit Surgery

Regular clinic by Ian Bell

Logic levels – Part 2

Last month, we looked at some basic concepts related to logic levels (logic voltages) including (briefly) the concepts of positive and negative logic, the input and output voltage ranges for 0 and 1 for logic gates, and noise margins, which indicate how much voltage shift can be tolerated without causing errors. We looked at the basic internal circuitry of TTL and CMOS gates, and at the history of digital technology that has led to the current situation where the majority of logic circuits are CMOS, but operate on a variety of different supply voltages (however, other technologies such as TTL are still available).

The wide range of logic families and operating voltages leads to potential problems when attempting to interface ICs from different families, or those which operate on different supply voltages. This is a common problem in circuit design. For example, having selected a microcontroller we find that the peripheral devices most suited to a project operate at different supply voltages and have incompatible logic levels. Last month, we concluded with a brief discussion on a couple of simple techniques for interfacing old 5V LS TLL to HC CMOS; however, this does not cover all situations that occur with more-modern devices. As we mentioned last month, the best solution to interfacing circuits with incompatible logic levels is often to use one of the many logic-level-translation ICs which are available. Logic-level translation is a common issue in commercial design, so the semiconductor manufacturers provide plenty of devices that deliver solutions.

This month, we will start by looking at the general forms of translation circuit that are available and then consider some example devices from various manufacturers. The devices are simply examples; we are not attempting to recommend these above any others. Often, similar devices will be available from other manufacturers, and, as always, anyone requiring a device for a project should research what is available and select the most appropriate for that design. However, this article will provide you with some idea of what to look for in various circuit scenarios.

As just mentioned, there are a number of different types of logic-level-translation circuit, some key examples are illustrated in Fig.1 to 5. In all these cases there are two circuits operating on different supplies (circuit 1 and circuit 2), where either circuit could have the higher supply voltage. In general, translation from a logic level on a low supply voltage to a higher one is called 'up translation'. For a higher to a lower voltage it is called 'down translation'.

Unidirectional translators

Fig.1 and Fig.2 show unidirectional circuits – this is where the signal travels in only one direction – in these examples, from circuit 1 to circuit 2. Unidirectional translators may have power supply connections to both supplies (dual supply) or just to the supply associated with the translator output (single supply). Translators requiring a single supply are convenient in situations where the physical implementation means access to the source circuit supply is difficult. Using dual circuit supplies potentially allows the designers of the translator chip to provide more optimal behaviour, such as low power consumption over a wide range of supply voltages.

The unidirectional translation circuit in its most basic form is simply a buffer (a logic gate with a single output, whose value is equal to that of its single input). Translation chips may have several parallel buffers for translating multi-bit data (or multiple individual signals). Functions other than simple buffers are available, including inverting buffers and buffers with tri-state outputs (to facilitate connecting the translator output to a shared data bus). Fig.1 and Fig.2 show a possible enable signal, which would be used by tri-state translators. Multiple-input logic gate translators (eg, NAND or NOR) are also available, which, for example, allow efficient combining of simple 'glue logic' with voltage translation using the same IC.

Bidirectional translators

Fig.3 and Fig.4 show bidirectional logic translators. Bidirectional signals are common in digital circuits, in particular in the context of shared data buses and serial peripheral interfaces, such as I^2C, which are used for communication between microcontrollers and peripheral devices. There are two types of bidirectional logic-level translators – those which have a direction control (Fig.3) and those which automatically sense the signal direction (Fig.4). The controlled-direction level translators may handle multiple bits under a single direction control. Automatic direction sensing is on a per-bit basis. Both types (with and without direction control) may have an enable input to 'tri-state' (also called 'three-state' or '3-state'), that is disconnect or set to high impedance all the outputs (in both directions).

Finally, in terms of general translator circuit types, there are ICs referred to as

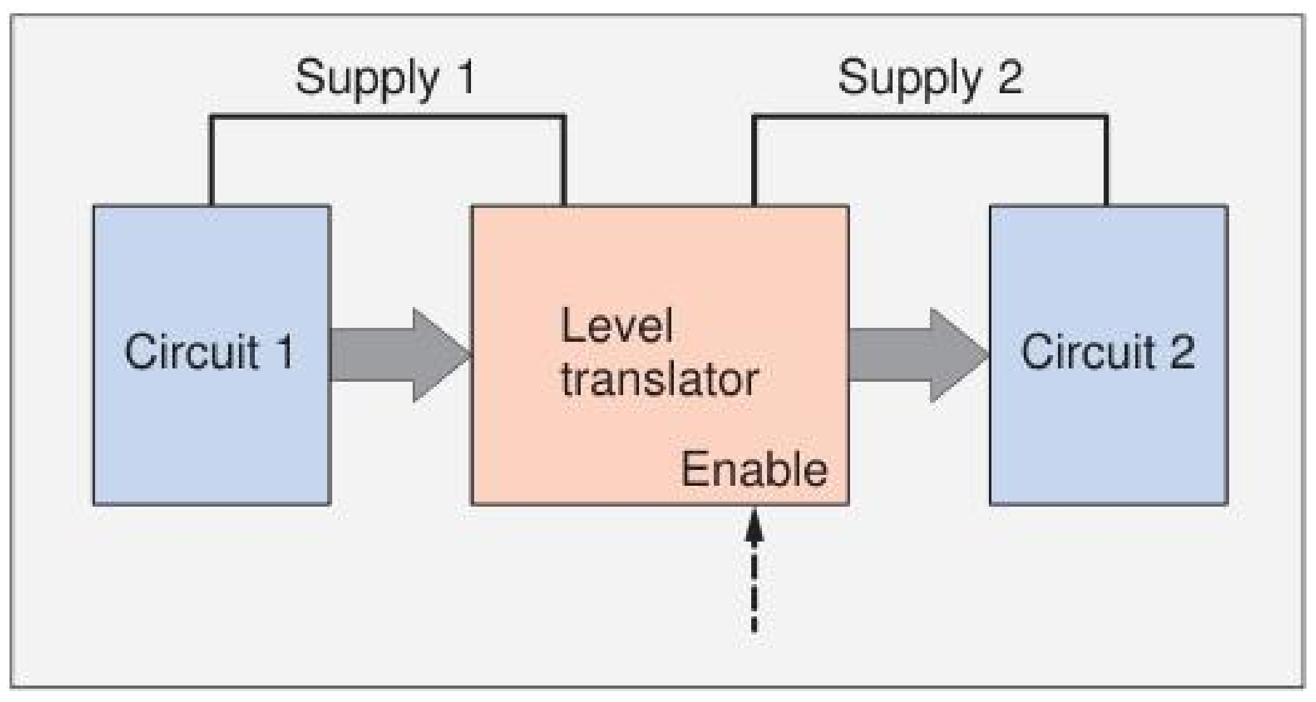


Fig.1. Dual-supply unidirectional level translator.

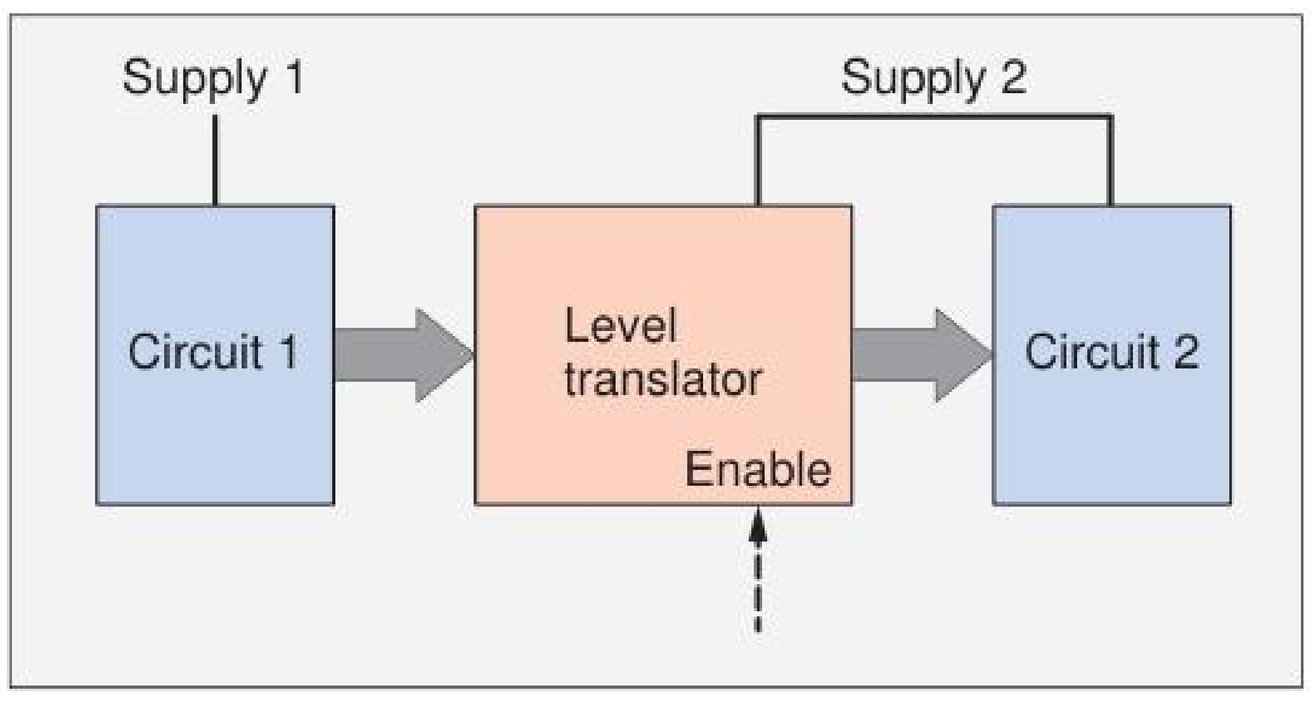


Fig.2. Single-supply unidirectional level translator.

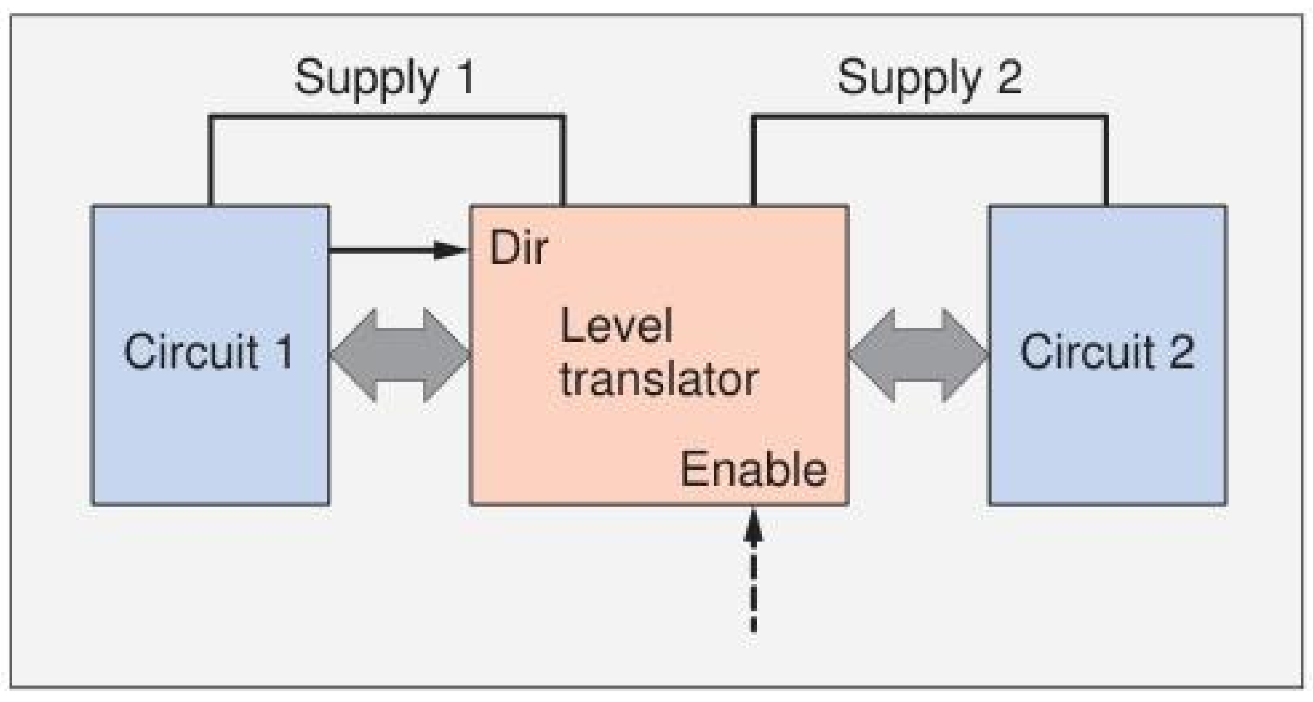


Fig.3. Bidirectional level translator with direction control.

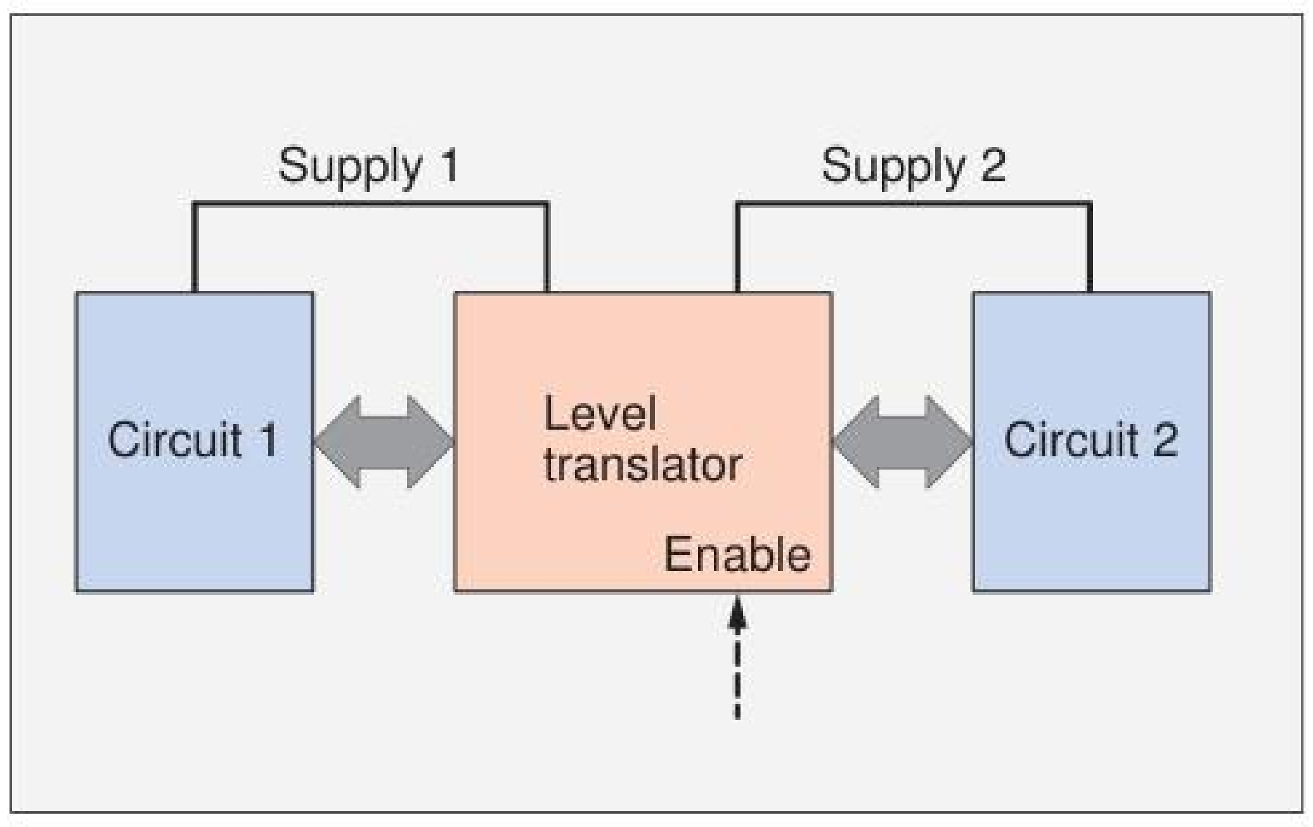


Fig.4. Bidirectional level translator with automatic direction sensing.

'application-specific level translators'. These devices are aimed, as their name suggests, at level translation in specific situations; for example, interfacing a processor to a SIM card. Typically, such situations require a mix of unidirectional and bidirectional level shifters and may also benefit from specific control signals to the level translator (eg, to implement a shutdown mode) – see Fig.5.

Auto-direction bidirectional level translators

Although various enhancements are used, the level translators in Fig.1 to Fig.3 can be implemented by circuits that are similar to standard logic gates and tri-state buffers. However, the circuits used for automatic direction bidirectional sensing can be somewhat different, so we will look a commonly used circuit of this type in more detail. The basic form of the circuit is show in Fig.6. This example shows one with 3.3V and 5.0V supplies, but the same approach can be used for other voltage translations, keeping the relative direction for low-to-high voltage the same. The circuit can be built using discrete MOSFETs and resistors, but is commonly implemented in level-translation ICs, where various enhancements may be included.

The circuit in Fig.6 operates as follows for transmission of data from the lower-voltage system to the higher-voltage system. When the lower-voltage system outputs a logic 1 (at 3.3V in this example), the MOSFET gate-source voltage is zero; so it will switch off. Under this condition the input to the higher-voltage system is pulled up to the supply voltage (5V in this case) by R2, and thus sees a logic 1 as required. When the lower-voltage system outputs a logic 0 (0V), the MOSFET gate-source voltage is equal to the lower supply voltage (3.3V here), so the MOSFET is switched on and the higher-voltage input is pulled down to 0V by the low drain-source resistance of the switched-on transistor. Thus, a logic 0 is seen by the higher voltage system, as required.

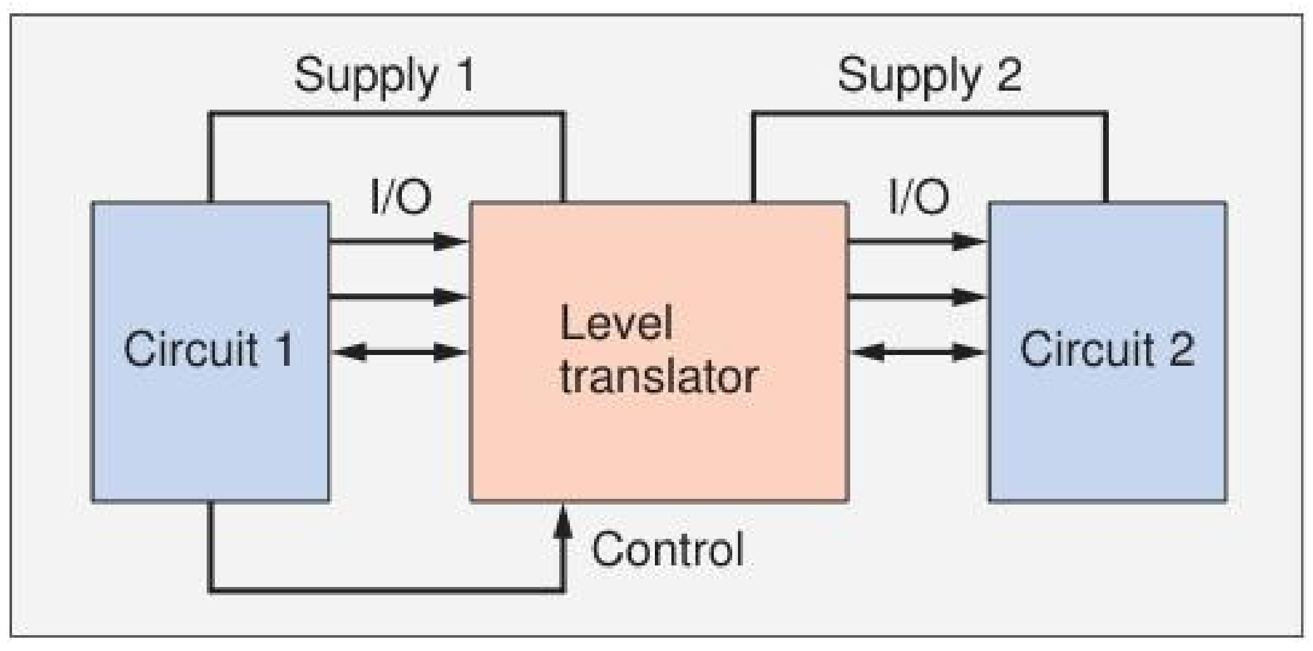


Fig.5. Application-specific level translator – example with a mix of unidirectional, bidirectional signal translation and translator control signal from circuit 1.

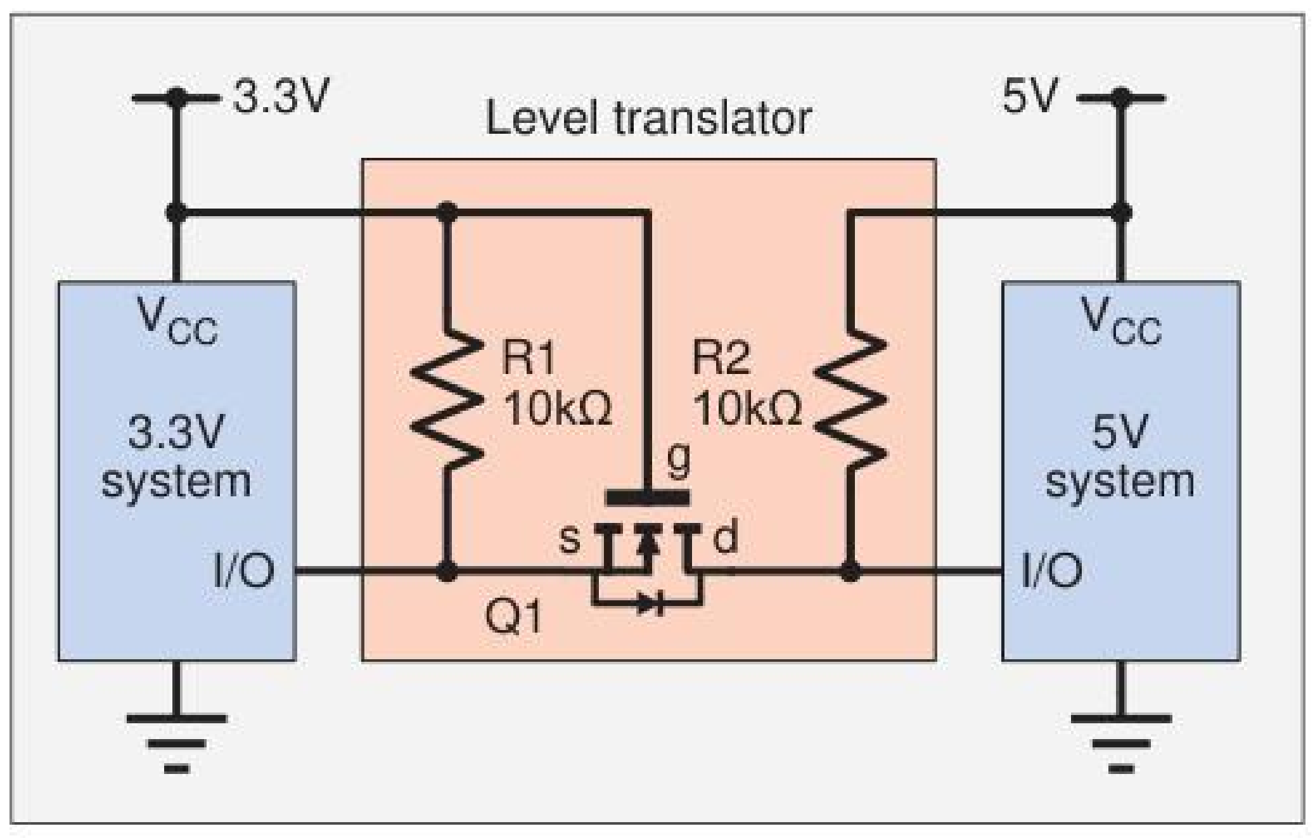


Fig.6. Basic direction-sensing bidirectional level translator.

The circuit in Fig.6 operates as follows for transmission of data from the higher-voltage system to the lower-voltage system. If the higher-voltage system outputs a logic 1 (5V here), then assuming (given that the high side is transmitting) that the low-voltage system is not actively outputting a logic 0, the MOSFET will be off, so the input to the low-voltage system will be pulled up to the supply voltage (3.3V here) by R1, giving a logic 1 as required. When the higher-voltage system outputs a logic 0 (0V) the MOSFET substrate diode conducts (via R1), pulling the lower-voltage system's input down to about 0.7V. This produces a positive gate-source voltage (of about 3.3 – 0.7 = 2.6V in this case), which is sufficient to turn on the MOSFET. The low drain-source resistance of the switched-on transistor is then able to pull the voltage at the input to the lower-voltage system even lower, resulting in a logic 0, as required.

A problem with the circuit in Fig.6 is that low-to-high logic-level transitions can be slow. CMOS circuit inputs and the wiring connecting circuits together appears as a capacitive load on the outputs driving them. To change the logic level, this capacitance has to be charged or discharged and this occurs through some amount of output resistance, leading to an RC time constant that determines how fast the logic level can change. The pull-up resistors in Fig.6 are relatively large compared with the effective resistance of typical logic gate outputs, resulting in slow transition when the resistors are relied on to pull up the node to logic 1.

The problem can be overcome using the circuit shown in Fig.7. Here a logic-0-to-1 transition on the side of the translator receiving an input triggers a one-shot (monostable) to produce a short pulse (typically in the order of a few tens of nanoseconds). The pulse activates a MOSFET switch, which temporarily bypasses the pull-up resistor on the side of the translator producing the output, increasing available current, and reducing the time taken to charge the capacitance of the output node. When using this translator circuit, care has to be taken not to reverse the signal direction while the one-shot is active, particularly to drive a logic 0, as this will create a signal contention and potentially high current flow.

The NLSV8T244 dual-supply unidirectional translator

The NLSV8T244 is an 8-bit dual-supply unidirectional level translator from ON Semiconductor. The functional diagram and pin connections are shown in Fig.8. The device has two power supplies: V_{CCA} for the input port (A), and V_{CCB} for the output port (B). Both supply rails can be in the range 0.9V to 4.5V, allowing very flexible logic voltage translation. The NLSV8T244 has an active low enable input ($\overline{\text{OE}}$) that can be used to set the outputs to a high-impedance state. The outputs also go high impedance if there is no supply on V_{CCB}. As indicated by the circuit structure in Fig.8, the $\overline{\text{OE}}$ input is referenced to V_{CCB}, but this and all inputs are over-voltage tolerant (with respect to the applied supply voltage) up to a maximum of 4.5V. The NLSV8T244 is available in a few package options, including SOIC–20 W, which has a 1.27mm (0.05-inch) pin spacing. There are various '244' devices available from different manufacturers, with the same basic circuit structure and function, but different numbers of bits and supply voltage ranges. Various other dual-supply unidirectional level translators have a similar structure.

LV1T series single-supply unidirectional translators

The LV1T series of CMOS devices from Texas Instruments provides an example of single-supply unidirectional logic-level translation. Each chip in the series

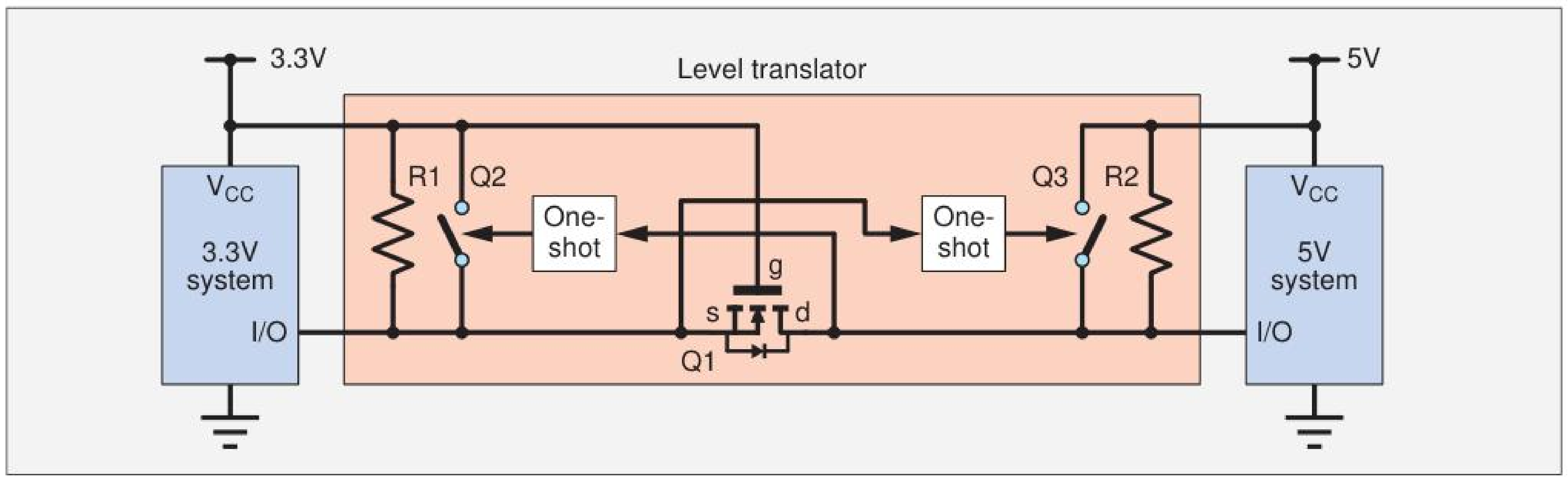


Fig.7. Direction-sensing bidirectional level translator with accelerated switching.

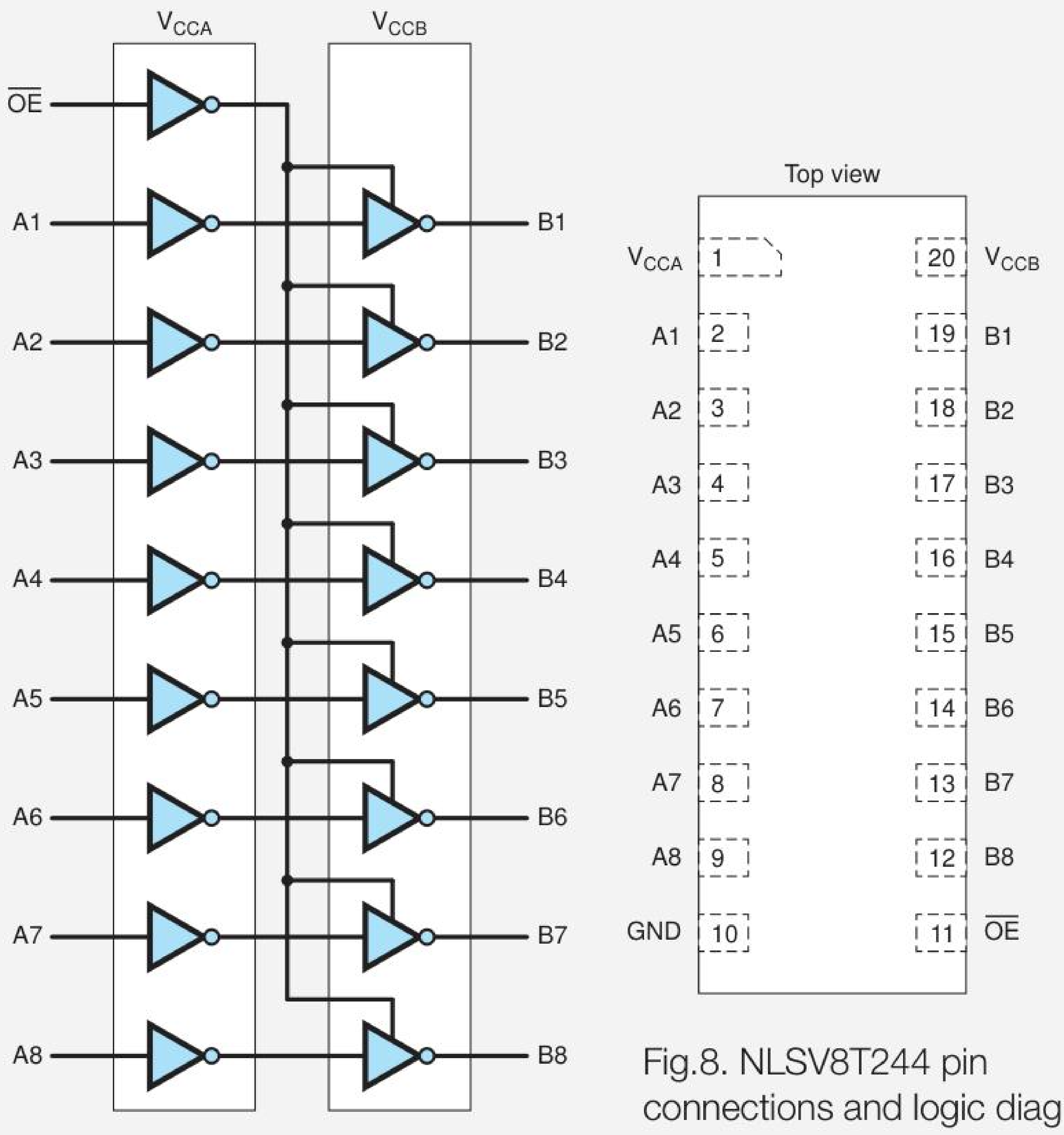


Fig.8. NLSV8T244 pin connections and logic diagram.

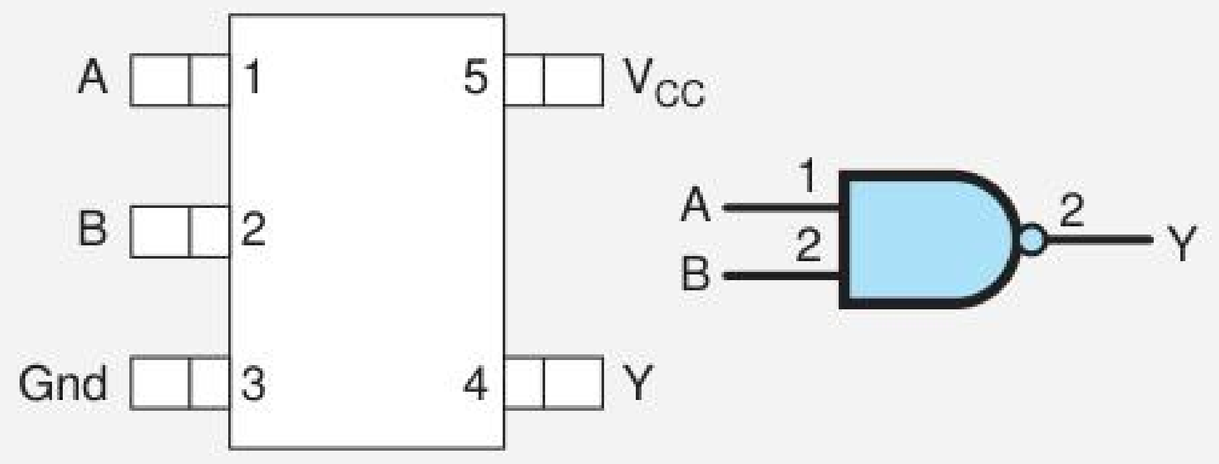


Fig.9. Example LV1T device pin connections and logic diagram – the SN74LV1T00 NAND gate.

provides a single logic function, together with logic translation – nine different single gates are available in the series – see Table 1. The data sheet descriptions for the NAND, NOR, AND and OR gates include the term 'positive' to indicate they are positive logic. As discussed last month, this means the logic 1 is at the more positive voltage level, which is the most common convention. These gates, and the exclusive-OR (XOR), all have two inputs. A possible issue with the LV1T series devices for some home constructors is its small size, although this is a common challenge with many devices which are only available in tiny surface-mount (SMT) packages. From the perspective of commercial designs, the point of producing single-gate ICs if of course the small space they can take up on a board compared with the older series where typically a package contained four 2-input gates. The LV1T series is available in a 5-pin SOT-23 package, which is only 2.9 × 1.6mm, or the even smaller SC70 package which is 2.0 × 1.25mm. The package layout and logic diagram are shown in Fig.9.

The output logic levels of LV1T-series devices are typical for CMOS devices and are related to the supply voltage, which can be one of the standard voltages: 1.8V, 2.5V, 3.3V or 5V. These devices can perform a number of both up and down logic-level translations.

LV1T up and down translation

The LV1T devices achieve up translation because they are designed with input-high logic levels lower than typical for the given supply voltage. For example, with a supply voltage of 3.3V a typical CMOS gate would have a logic 1 input level of at least 2.3V (about 0.7 of the supply voltage). However, the LV1T devices, when operating on 3.3V, have a logic 1 input threshold of about 1.0V. This allows a signal from a 1.8V logic output to be translated up to 3.3V logic levels. The following up translations are available – the second voltage is also the chip's supply voltage:

1.8V to 2.5V
1.8V or 2.5V to 3.3V
2.5V or 3.3V to 5V

Last month we mentioned that a potential problem with up translation is that the low-level input appears as a poor logic 1 or intermediate input level to the device operating on the higher supply. This can cause high current flow because both NMOS and PMOS transistors in the gate may switch on. The low threshold of the LV1T devices avoids this problem and current consumption is at or below the specified value for all valid CMOS logic 1 inputs for the various up translations.

The LV1T series devices have 5V-tolerant inputs – the inputs can be at voltages above the supply voltage, up to 5.5V. This facilitates down translation, with the available level conversions being as follows, with, again, the 'to' voltage also being the supply voltage:

2.5V, 3.3V, or 5V down to 1.8V
3.3V, to 5V down to 2.5V
5V down to 3.3V

The two-input gates in the LV1T series devices are able to translate two separate logic levels to a third output level (and either can be an up or down translation). Texas instruments suggest that a useful example application for this is in systems where a microcontroller has to monitor multiple power management ICs and needs

Table 1: Devices in the LV1T series of single-gate, single-supply logic-level translators

Device	Function
SN74LV1T 00	NAND
SN74LV1T 02	NOR
SN74LV1T 04	Inverter
SN74LV1T 08	AND
SN74LV1T 32	OR
SN74LV1T 34	Buffer
SN74LV1T 86	XOR
SN74LV1T 125	Tri-state buffer active-low enable
SN74LV1T 126	Tri-state buffer active-low enable

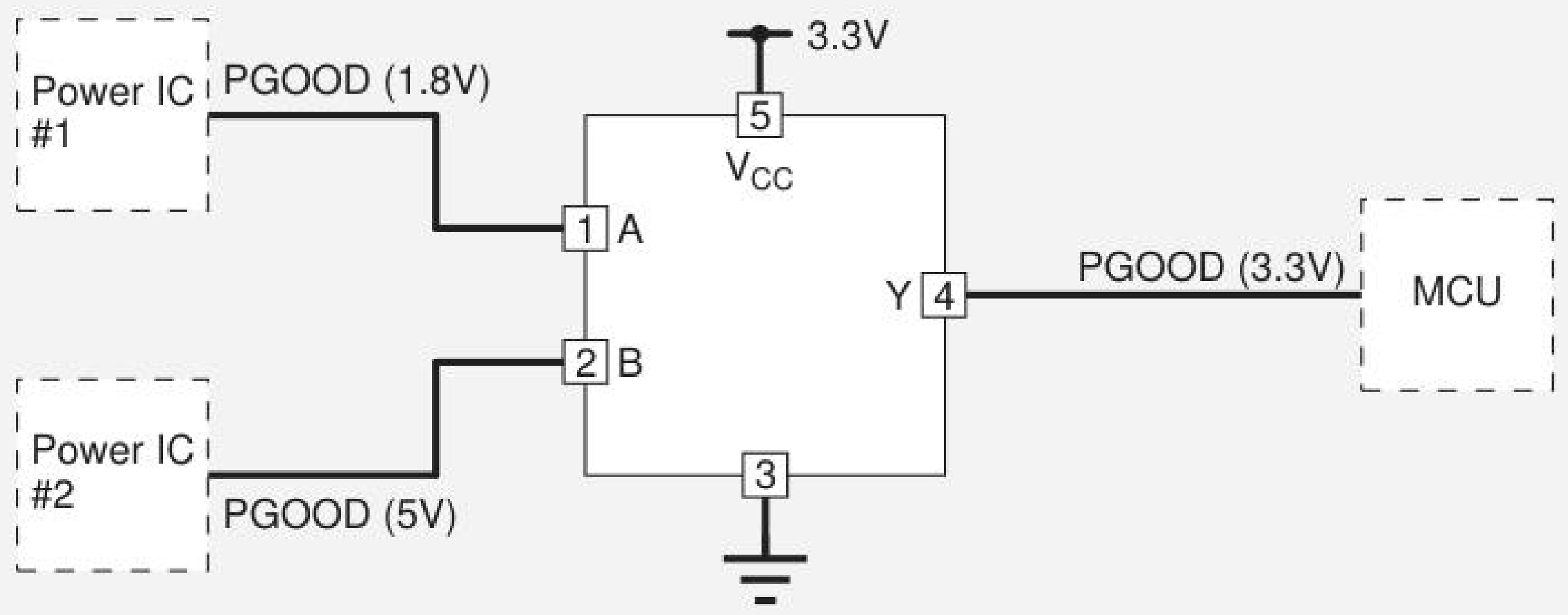


Fig.10. Example circuit from Texas Instruments in which a LV1T series AND gate translates two different logic voltage input levels (1.8V and 5V) to a third voltage output level (3.3 V).

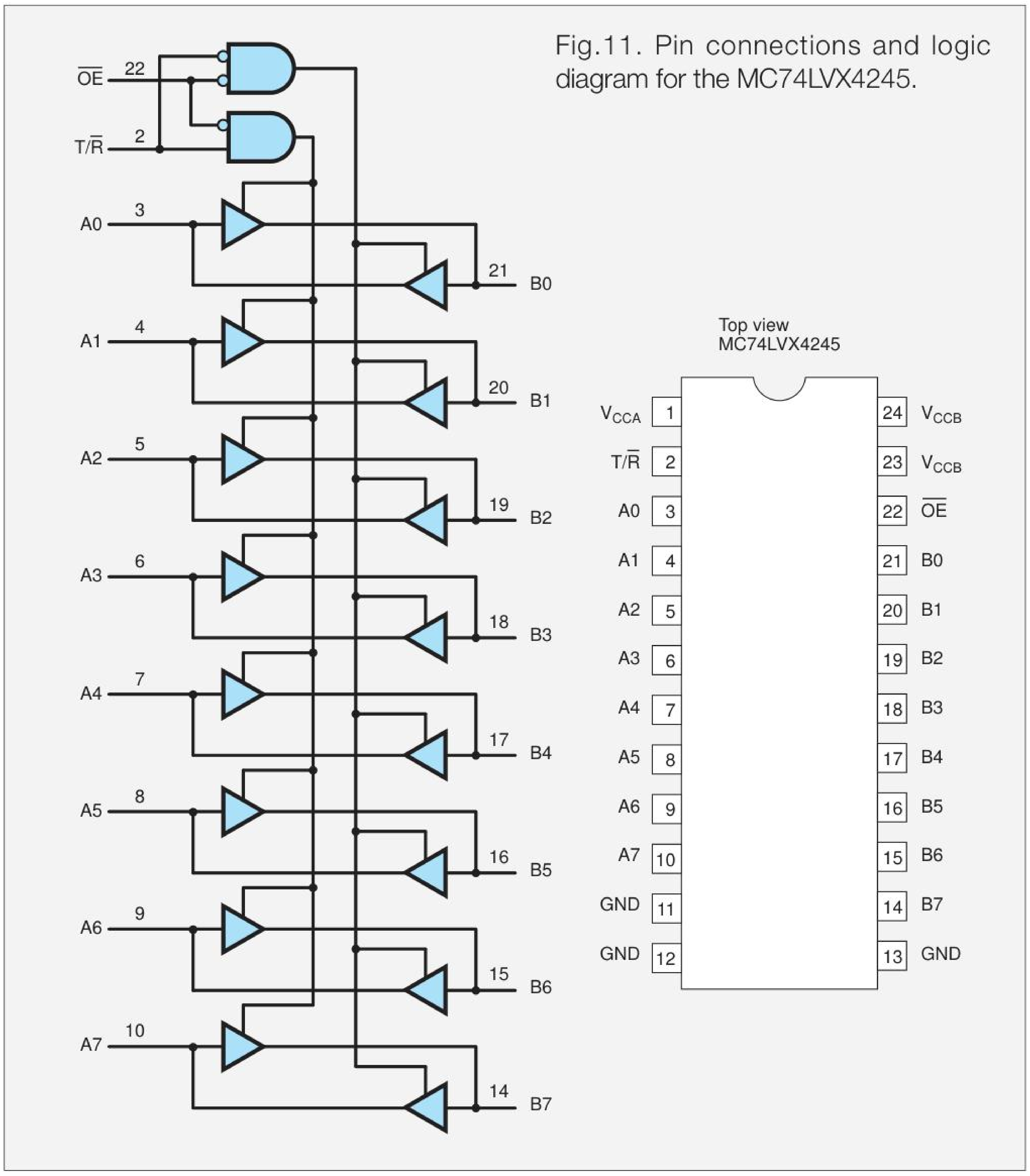

$\overline{OE}$ 22
$T/\overline{R}$ 2
A0 3
A1 4
A2 5
A3 6
A4 7
A5 8
A6 9
A7 10
21 B0
20 B1
19 B2
18 B3
17 B4
16 B5
15 B6
14 B7
Top view
MC74LVX4245
V_{CCA} 1
$T/\overline{R}$ 2
A0 3
A1 4
A2 5
A3 6
A4 7
A5 8
A6 9
A7 10
GND 11
GND 12
24 V_{CCB}
23 V_{CCB}
22 $\overline{OE}$
21 B0
20 B1
19 B2
18 B3
17 B4
16 B5
15 B6
14 B7
13 GND

Fig.11. Pin connections and logic diagram for the MC74LVX4245.

to know when two supplies (other than its own) are up and ready to use. As was indicated last month it is common in modern systems for there to be multiple logic supply voltages. In such situations it is often necessary to correctly sequence their switch-on, or for the main processor to know when all supplies are up before attempting system operations. The example circuit is shown in Fig.10.

MC74LVX4245 bidirectional level translator

The MC74LVX4245 is a dual-supply, bidirectional, octal level translator with tri-state outputs. The logic diagram and pinout are shown in Fig.11. This device is from ON Semiconductor and is designed for interfacing between two tri-state buses operating on 5V and 3.3V logic. There are various '245' devices available with the same basic circuit structure and function, but different numbers of bits and different voltage translations.

The MC74LVX4245 has two 8-bit input/tri-state output ports, A and B, associated with supplies V_{CCA} (5V) and V_{CCB} (3.3V) respectively. The $T/\overline{R}$ (transmit/receive) input is the direction control. When $T/\overline{R}$ is high, data is transferred from A to B; when it is low, transfer is from B to A. The $\overline{\text{OE}}$ input is used to enable the output (when $\overline{\text{OE}}$ is low), whichever port (A or B) is currently the output. A high on the $\overline{\text{OE}}$ input puts both the A and B I/O pins into a high-impedance state. The control inputs can be operated at either the low or high voltage levels. ON Semiconductor recommend powering on V_{CCA} before V_{CCB}, as high supply currents can flow if the power-up is in the opposite order – refer to the datasheet for more details.

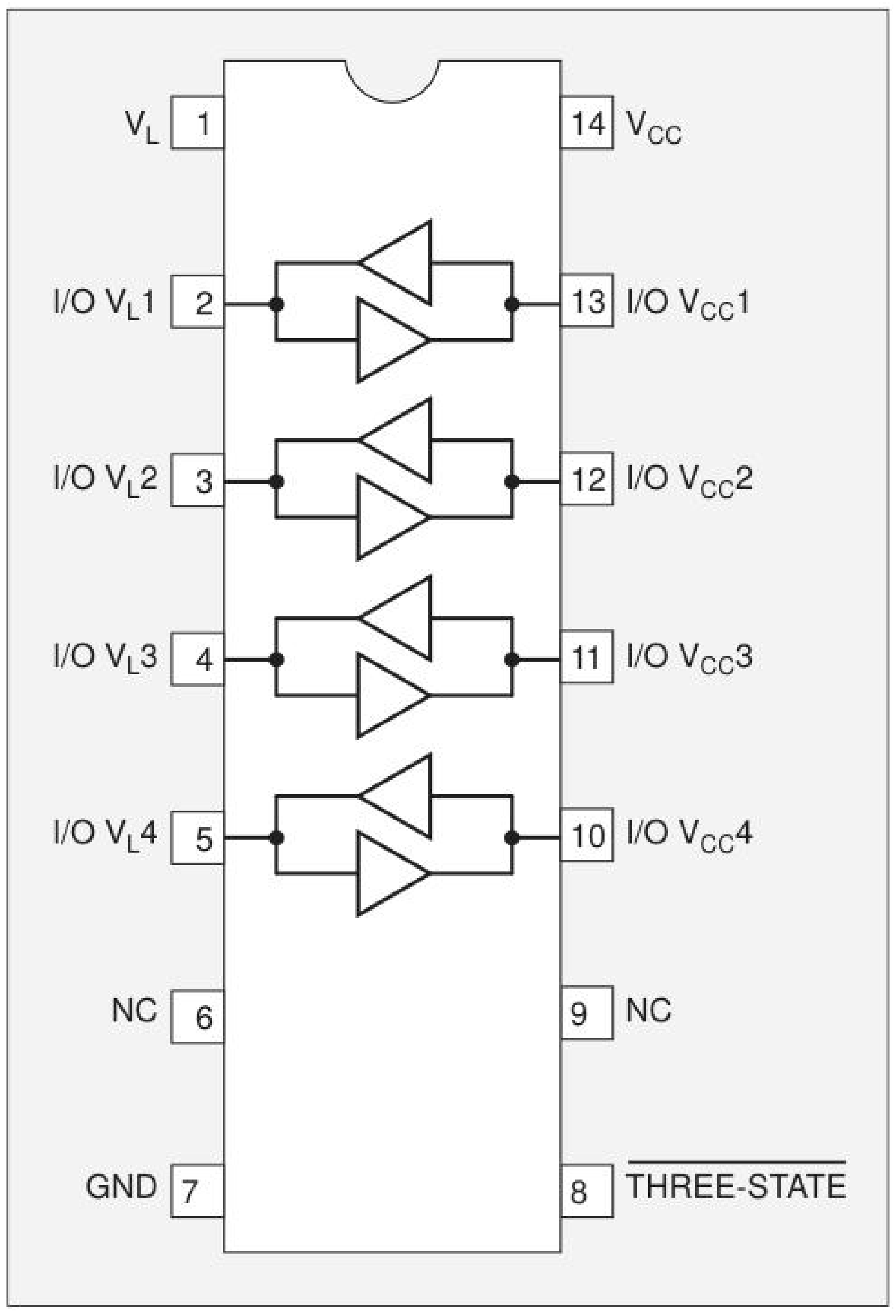

V_L 1
I/O V_L1 2
I/O V_L2 3
I/O V_L3 4
I/O V_L4 5
NC 6
GND 7
14 V_{CC}
13 I/O V_{CC}1
12 I/O V_{CC}2
11 I/O V_{CC}3
10 I/O V_{CC}4
9 NC
8 $\overline{\text{THREE-STATE}}$

Fig.13. Pin connections and logic diagram for the MAX3377E and MAX3378E (TSSOP-14 package version).

The typical use of the MC74LVX4245 is shown in Fig.12. The device acts as a link between two shared tri-state buses operating on 3.3V and 5.0V. Devices from one bus can read or write data from the devices on the other. Typically, the processor would be on the lower-voltage bus, together with peripherals of a similar generation operating on the same voltage. Other peripherals (possibly older technologies) would be on the higher-voltage bus.

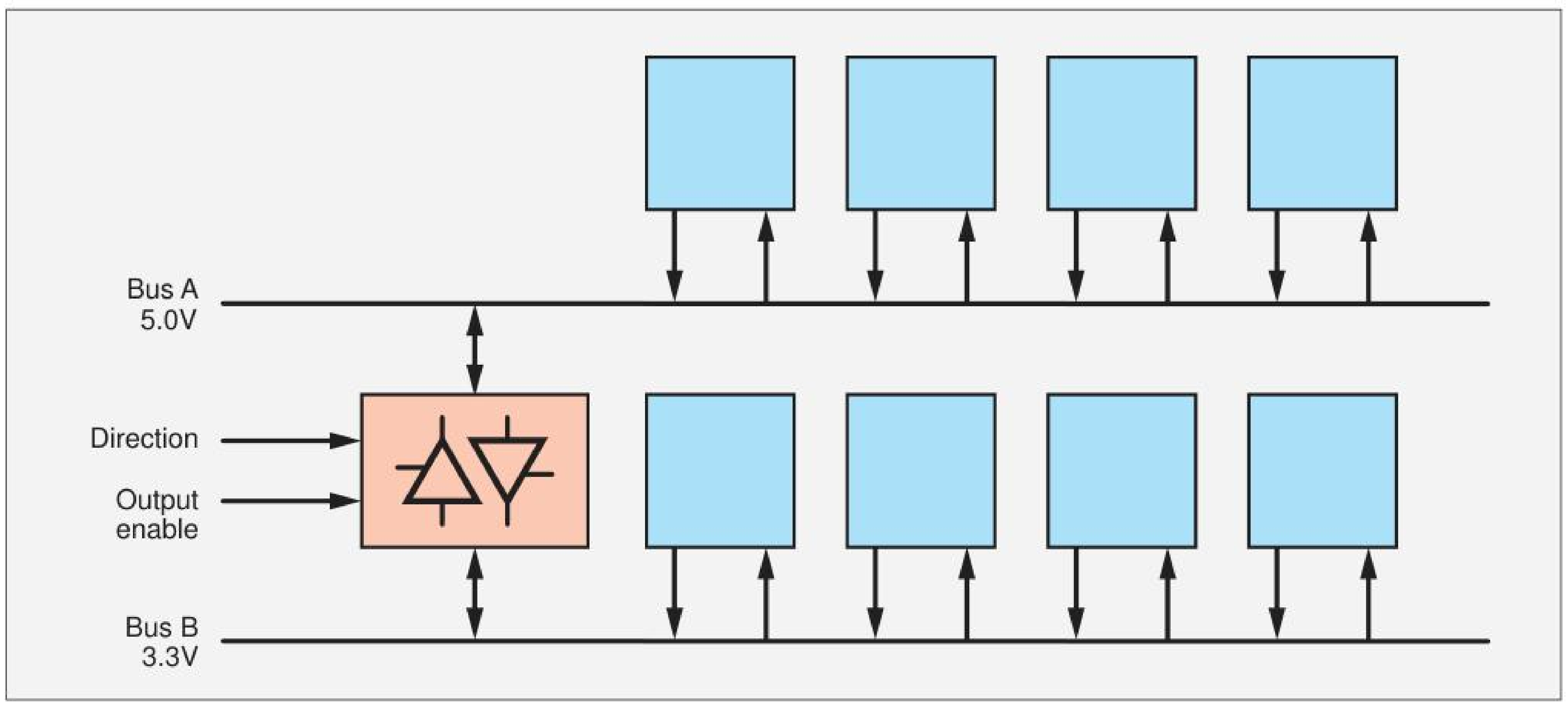

Bus A
5.0V
Direction
Output
enable
Bus B
3.3V

Fig.12. Typical use of MC74LVX4245 as a bus transceiver for connecting two shared buses operating at different voltages.

MAX3377E and MAX3378E quad bidirectional auto-direction level translators

The MAX3377E and MAX3378E from Maxim Integrated are quad bidirectional automatic direction-sensing level shifters. Their pinout and logic diagram is shown in Fig.13. The MAX3377E uses a circuit similar to Fig.6 for each translator. The MAX3378E includes one-shots for accelerating logic switching and each translator has a circuit similar to Fig.7. For both chips, the low-voltage (V_L supply pin) side can be from 1.2V to 5.5V and the high-voltage side (V_{CC} pin) can range from +1.65V to +5.5V. There

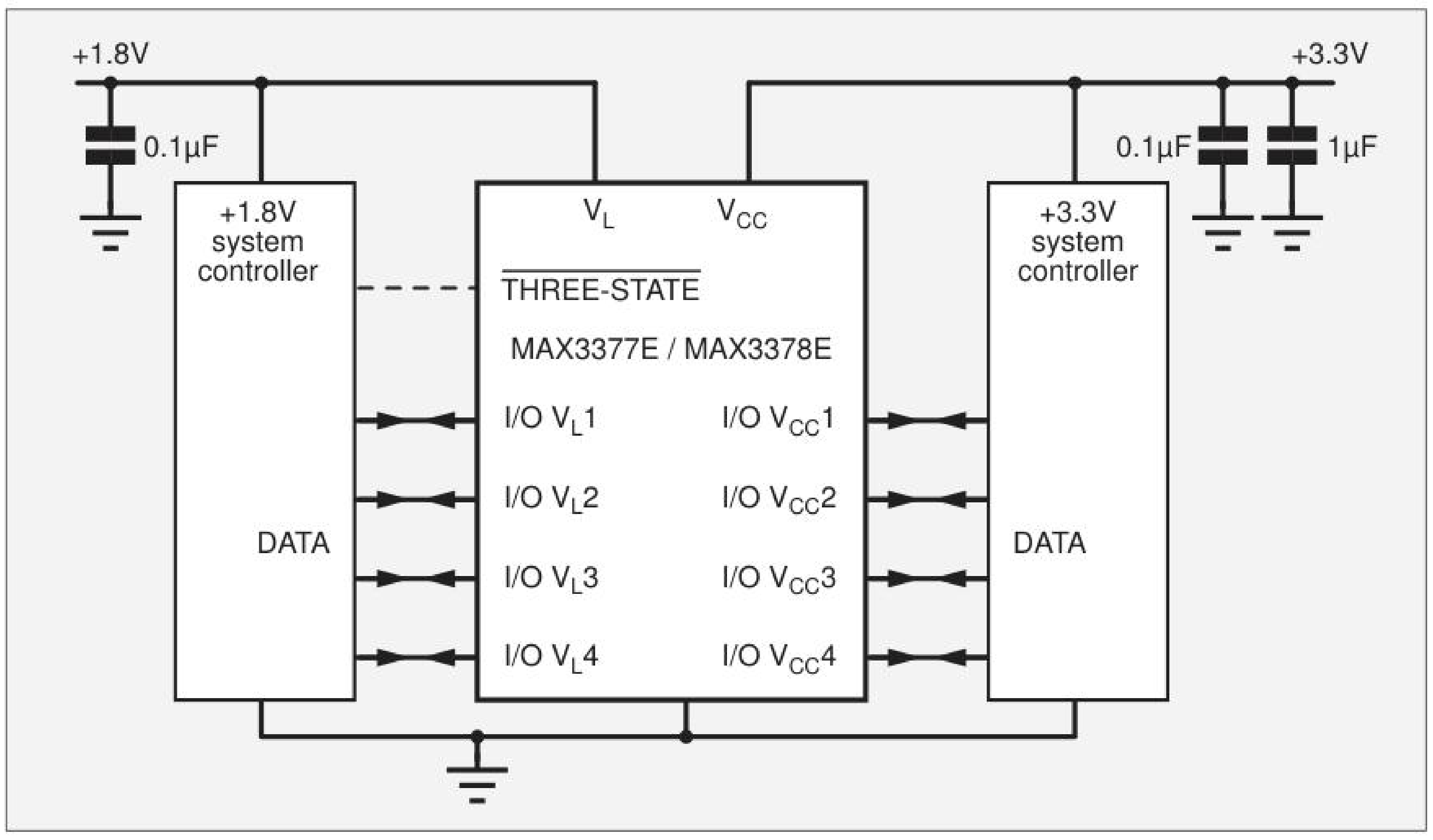

+1.8V
+3.3V
0.1µF
0.1µF
1µF
+1.8V system controller
VL
VCC
+3.3V system controller
THREE-STATE
MAX3377E / MAX3378E
I/O VL1
I/O VCC1
I/O VL2
I/O VCC2
DATA
I/O VL3
I/O VCC3
DATA
I/O VL4
I/O VCC4

Fig.14. Typical application circuit for the MAX3377E and MAX3378E.

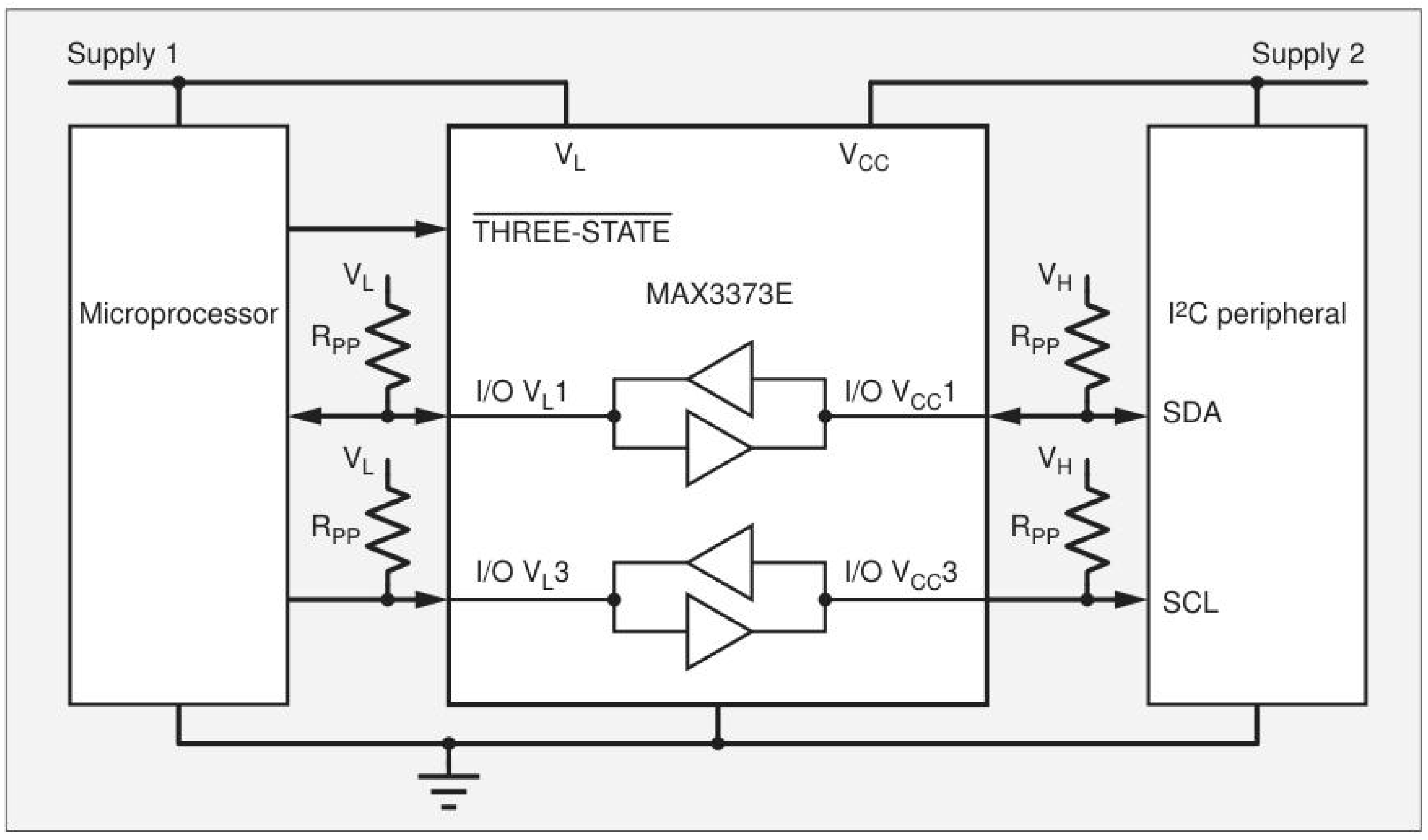

Supply 1
Supply 2
VL
VCC
THREE-STATE
MAX3373E
Microprocessor
VL
RPP
VH
RPP
I2C peripheral
I/O VL1
I/O VCC1
SDA
VL
RPP
VH
RPP
I/O VL3
I/O VCC3
SCL

Fig.15. Level translation of an I²C bus using a MAX3373E.

is a requirement that V_L is less than V_{CC} by at least 0.3V, but this does not have to apply during power-up transitions. These devices are available in TSSOP, TDFN and the very small micro (µ) chip-scale package (UCSP), which has ball grid array type connections under the package – see: **https://en.wikipedia.org/wiki/Ball_grid_array**

Both devices have an active-low tri-state control input ($\overline{\text{THREE-STATE}}$ pin) which puts all the I/O pins into a high-impedance state and reduces the supply current to the chip to less than 1µA. This works by disconnecting the internal 10kΩ pull-up resistors (see Fig.6 and Fig.7) from the supplies.

A typical application circuit for the MAX3377E and MAX3378E is shown in Fig.14. This example shows a 1.8V system controller (eg, microcontroller) communicating with a 3.3V system, but other voltage combinations would have a similar structure.

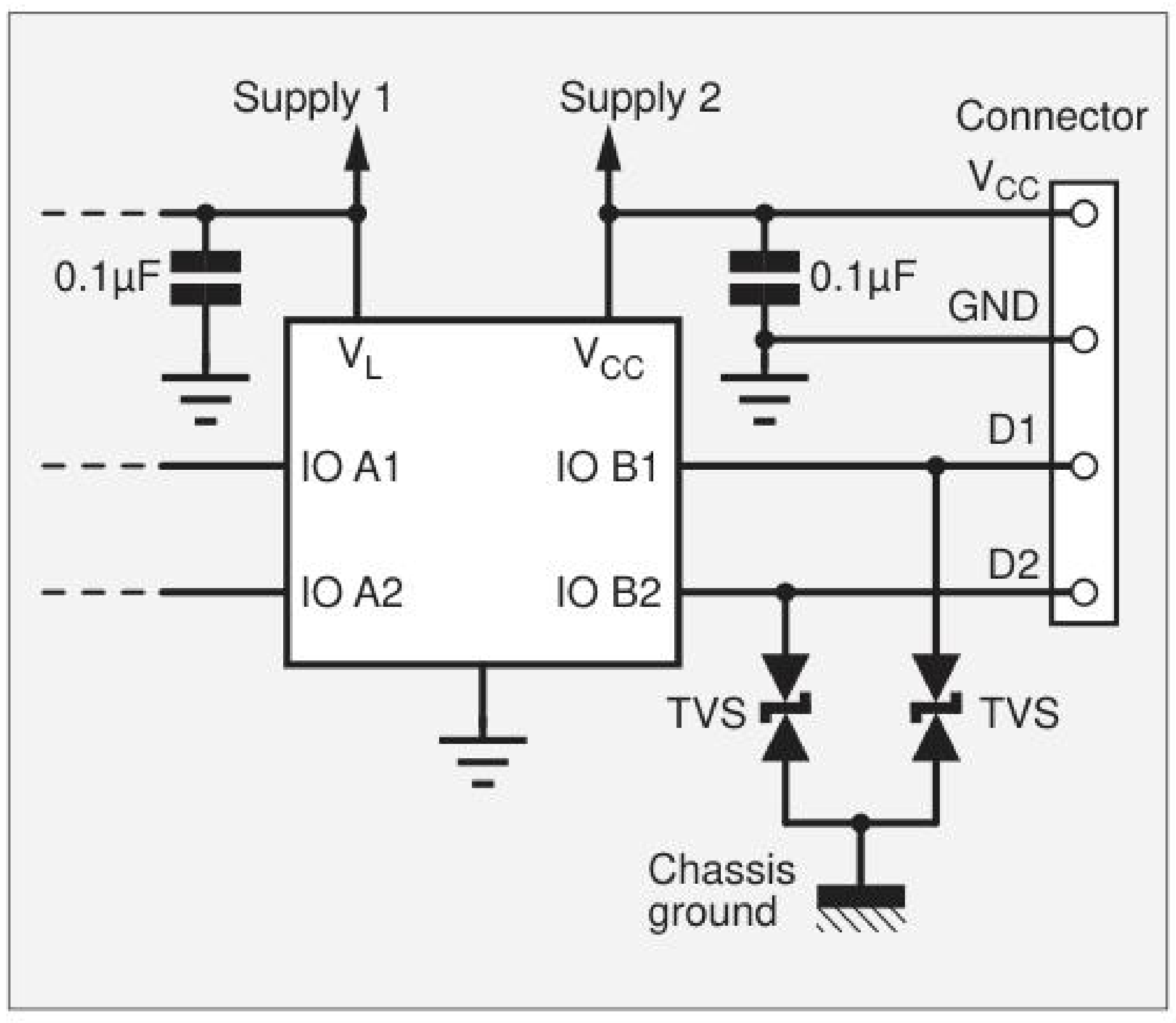

Supply 1
Supply 2
Connector
VCC
0.1µF
0.1µF
GND
VL
VCC
D1
IO A1
IO B1
D2
IO A2
IO B2
TVS
TVS
Chassis ground

Fig.16. Example circuit of level translator handling off-board signals via an I/O connector. TVS diodes provide protection; also note the decoupling capacitors.

Maxim also produce a dual version MAX3378E, the MAX3373E, which is suitable for level translation of I²C buses. An example circuit is shown in Fig.15, where a microprocessor on a relatively low supply voltage (Supply 1) is connected to a higher-supply-voltage I²C peripheral IC (such as an ADC or DAC) via the MAX3378E. Depending on the bus configuration, external pull-up resistors (R_{PP}) may be required (the internal pull-ups are 10kΩ) – refer to Maxim's documentation for details on resistor value selection.

Using level translators

Like all digital ICs, level translators should have supply decoupling capacitors placed close to them on the circuit board. Dual-supply level-translation ICs should be provided with supply decoupling capacitors on both supply pins. Supply decoupling capacitors filter supply noise and help prevents glitches, which may result in incorrect operation. A typical value for these capacitors is 0.1µF, but device data sheets may make specific recommendations. As with all digital circuit boards, power supplies must be connected via low-impedance routes, typically as wide areas of copper known as 'power and ground planes'.

If level translators are used to provide interfaces to circuits that are not on the same board then it is usually a good idea to provide some form of protection from transient voltage surges. This is particularly the case if I/O connectors will be plugged and unplugged by users. Protection is typically provided by adding reverse-biased diodes between the I/O and both supply and ground, or by using transient voltage suppression (TVS) diodes (bidirectional avalanche breakdown diodes) connected between the I/O and ground (see Fig.16). The protection devices should be placed close to the I/O connector and the route between the translator chip and I/O connector should be as short as possible to reduce both emission of, and susceptibility to, radio interference.

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Practically Speaking

Hands-on techniques for turning ideas into projects – by Mike Hibbett

PCB digital microscope

Components are getting smaller and none of us are getting younger, which means diminishing eyesight makes assembling electronic circuits increasingly difficult. In fact, even if you have youthful 20-20 vision, some SMD (surface-mount device) assembly has become almost impossible without aids.

In the 1980s, a typical surface-mount device measured 2.0 × 1.25 mm. As a young engineer, these components were no problem to solder before the first cup of coffee, but 30 years later and after a lifetime of caffeine and day-long sessions in front of a computer screen, reading glasses are not enough. Glasses are great for reading books and restaurant menus, but the fine motor control and clarity of vision required to place solder and position an iron tip precisely on these tiny components becomes increasingly challenging.

The solution is the inclusion of some form of desktop visual magnification. All professional PCB assembly houses use visual magnification tools in manual re-work and repair stations (mainly we suspect because the people employed in this work are more experienced, and therefore a little older!)

We were lucky to obtain an old Nikon Stereo PCB inspection microscope many years ago, and it probably cost over a thousand pounds when new in the 1970s. Its construction quality is fabulous and will probably continue to serve the next generation. It's a joy to work with and we have spent days at a time soldering boards while peering through it. These vintage microscopes are, however, very expensive when bought new, and good ones are hard to come by second hand. The author's microscope (shown in Fig.1) is over 40-years old and ones of a similar age still sell for over £200. So what are the options for people keen to obtain some assistance?

What to use?

There is a wide range of options available on the market within a reasonable price bracket and, depending on your needs, a perfectly adequate solution can be found for home use. Generally performance is linked to cost, and performance in this case means:

- Comfort in use
- Optical quality
- Magnification range
- Image capture to PC
- Physical build quality

First, let's talk about options to avoid. Low-cost 'watchmaker' glasses found on eBay are useless. They have a fixed magnification, and you have to have your face very close to the work surface, and hold your head still. Expect to burn your nose while soldering. Handheld lenses, popular and effective for reading books are cheap but require you to hold them – 'losing' one hand, and making soldering impossible.

Budget optics

A 10cm magnifying lens attached to a 'helping hands' stand like that in Fig.2 is a fair solution and prices start around £10, but of course they only give a single level of magnification. These are a reasonable starting point and we have one in our lab, mainly for soldering wires to connectors. They are of limited value for working with small surface-mount components, but at such a low cost are well worth adding to your collection of tools. At this price point it's also worth adding a ×3 magnification 'eye loupe', as seen in Fig.2 next to the helping hands.

Basic digital microscopes

Cheap digital PCB microscopes – essentially a webcam on a stand – have become the modern solution to the problem. The image is displayed on a computer screen that you place in front of your work area, or on a small LCD display mounted on the stand itself. Avoid the latter – these small LCD displays cannot provide the clarity required. Again, performance is linked

(Left) Fig.1. The author's high-quality Nikon PCB microscope; and (right) Fig.2. Helping hands magnifier and loupe – useful but basic.

to cost. The cheap ones have short focal lengths, which makes putting the soldering iron under them difficult or impossible.

There are other options available: large, desk-mounted lenses on angle-poise stands, some with integrated light sources, but again you are limited by a single magnification factor, and also there are no options for capturing images to a file. Despite the limitations, these will also be expensive, and not suited to kitchen-table development.

Instrument review

For us, a primary requirement for the microscope was the ability to save the image to a file, specifically for publication within this magazine. With this in mind we set a budget of around £100 pounds (but not below £80) – we wanted to avoid the obviously cheap end of the market.

It's difficult picking the good solutions from the bad by looking at an advert on the Internet. Prices range from £50 or so to several hundred – but since we were 'taking a risk', we chose to go with one that looked right, at a reasonable price – £120 delivered in this case. We searched through Amazon, eBay and Banggood. Our choice came from Banggood (Item ID 1377420 at: **http://bit.ly/pe-feb20-ps**).

We have made several purchases through Banggood before; the quality can be variable, but it is a stable and safe platform to make purchases on. As safe as any other Internet purchase, that is!

The instrument is called, 'HAYEAR 14 Million Pixels Full HD Color Screen Digital Magnifier Microscope 1 / 2.3 Inch Electron Digital Microscope Image Sensor With Bracket'. Let's be clear, this is not an 'electron microscope', digital or otherwise! This may be a translation error – perhaps they meant 'Electronic Digital Microscope'? It's advertised as a 14-million-pixel device, but this is sly marketing – it's a 2.1-megapixel camera; the saved image is simply scaled up in size by software. Sadly, no great surprise – that's the standard of honesty we have become accustomed to when purchasing on the Internet.

Delivery was a little quicker than the worst-case delivery stated, so pretty typical for Far-East shipments.

The packaging was excellent, and it appears to be a nice solid unit with capabilities beyond those of a simple webcam on a stand. This was a good start. You can see the device in action in Fig.3

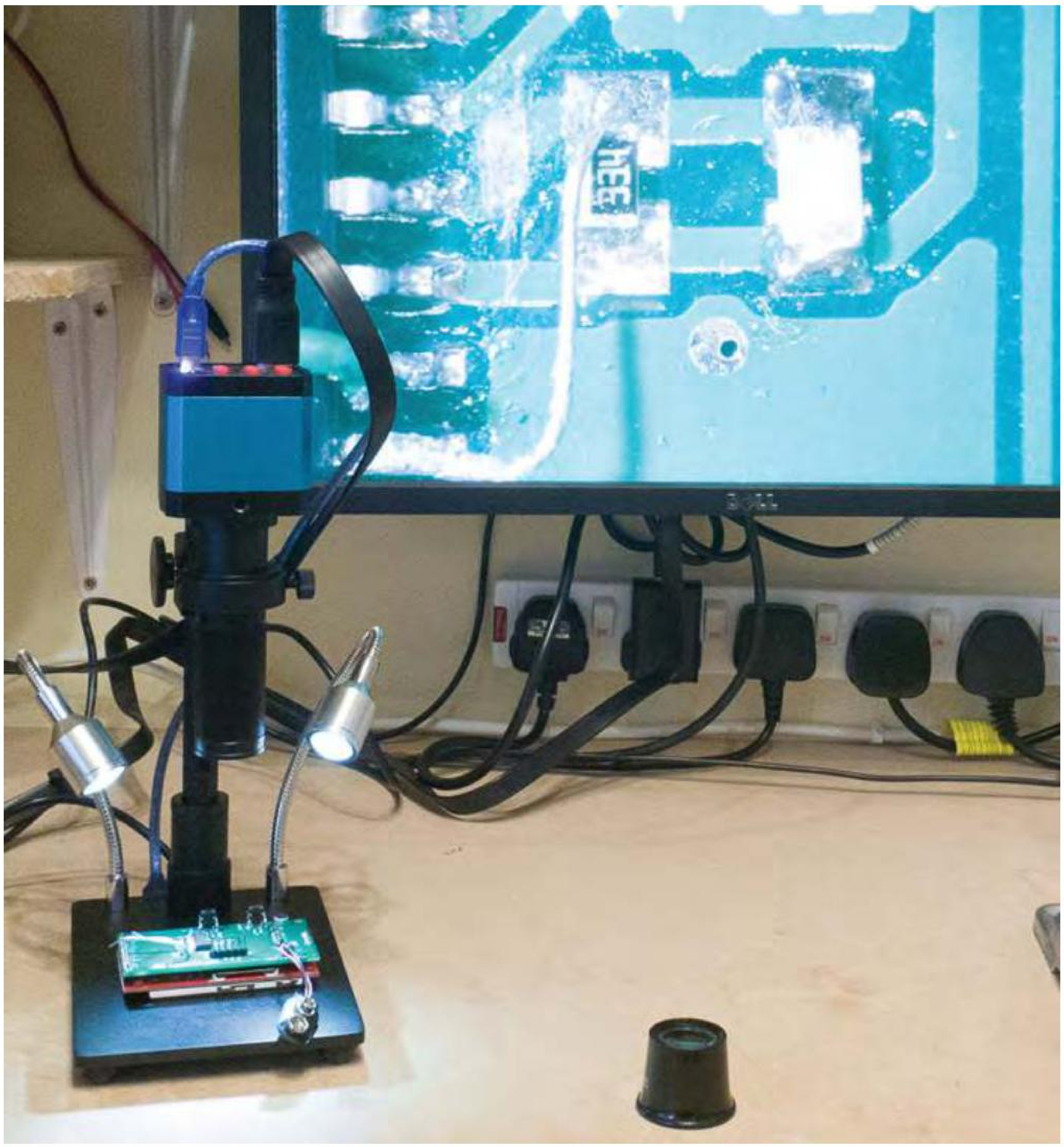


Fig.3. The digital microscope in use; the image is displayed on a large PC monitor.

A variety of cables are included: USB to supply power to the two LED lights in the base; another USB for camera power and image upload to a PC; and an HDMI cable for direct connection to a display. As the device has a micro SD-Media card for image storage we set the device up for the latter configuration. A USB power supply was provided, but it was for a US power socket, so we discarded it and used our own mobile phone charger power brick.

The addition of two light sources on flexible mounts is great; you can easily adjust both to find those hard-to-spot hidden dry joints. A variable resistor provides light intensity control, although with a poor range of setting – still, good enough.

The 2.1 megapixel image quality is excellent, and the camera does a fine job of displaying components and solder joints.

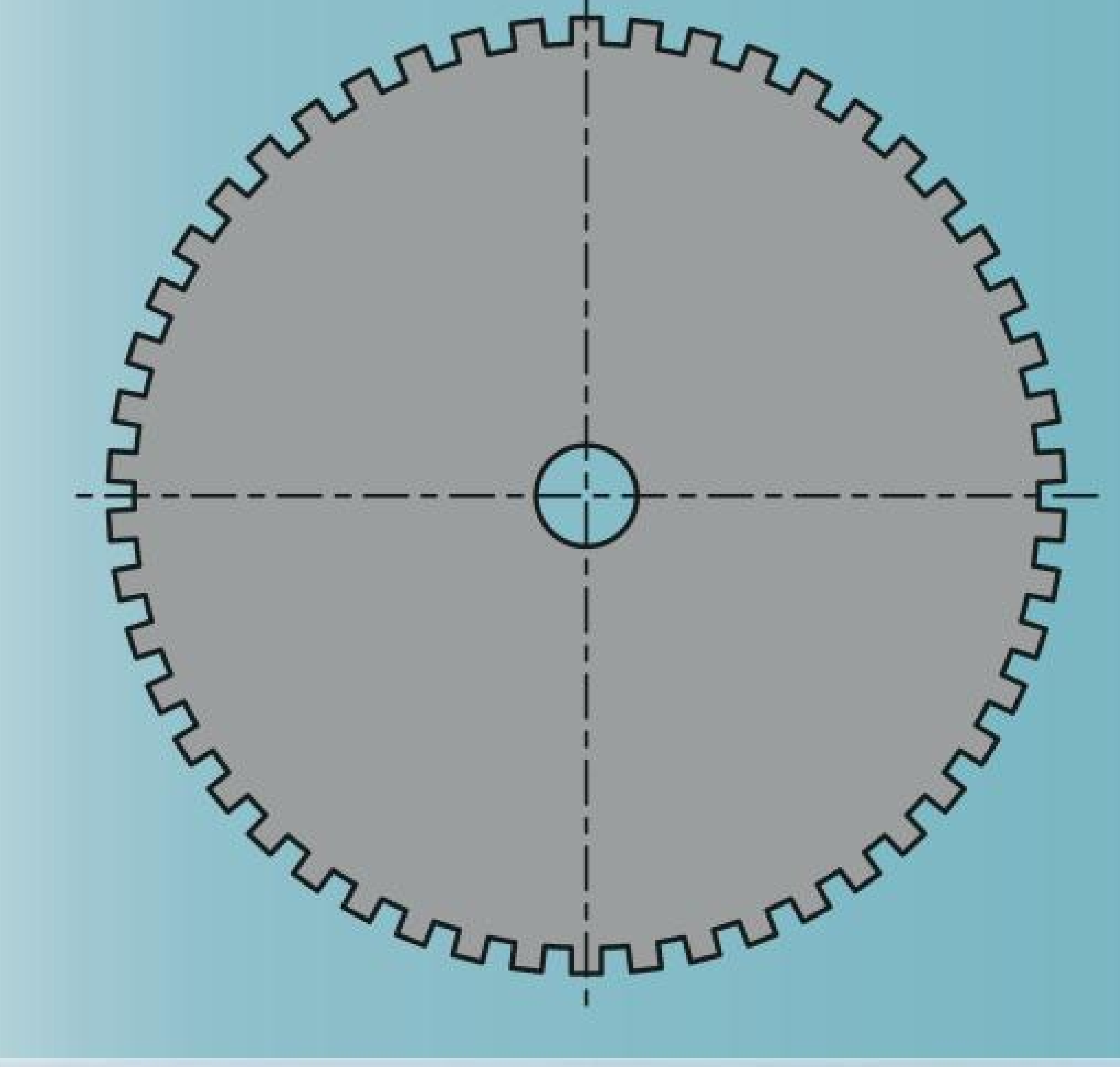
Good for PCB work

A key advantage of this microscope is the gap between the workspace and the camera; it's perfectly acceptable for soldering. It took about an hour to get comfortable looking at the computer screen (ie, away from the work surface), and for short periods of time it is excellent. If we have to spend hours soldering components, then the Nikon remains the preferred option – it's more comfortable to use, very simple to set up (ie, no setup) and is of a build quality that means it will be in use for decades.

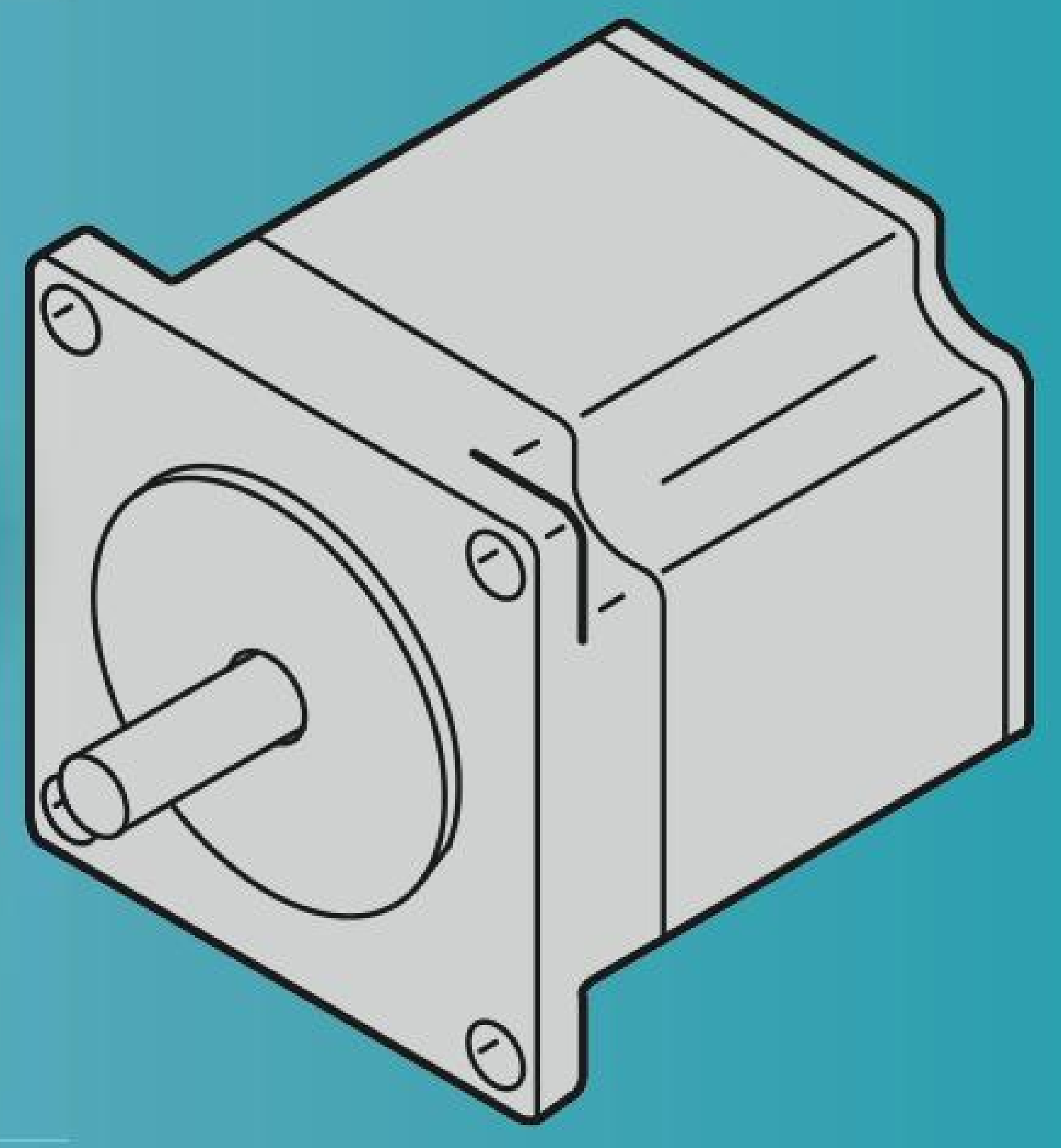
The build quality of the Banggood device is mixed. The electronics, camera and lights are fine. The rack and pinion provided to raise and lower the camera, less so. They are metal parts, but of cheap quality and they frequently stick going up, which indicates this is not going to last for many years. That's not a big concern; this device is ten-times cheaper than the Nikon microscope, and it offers many modern features. The system is modular, so you can move the camera and lighting to another platform at a later date if required.

The final interesting inclusion is a remote control. The handset repeats the functions on the camera, with the main features being to take a photo to an SD media card, or adjust the zoom level. The zoom feature is useful, but it's no magic bullet for adjusting image quality. For that, you need to adjust the camera height manually. From the highest point to the lowest, the basic optical zoom factor ranged from ×3 to ×10 magnification. That's perfectly acceptable, and software-controlled zoom can triple that.

In conclusion, was this worth buying? The answer is, it depends. If you need to move on from a set of 'helping hands', then you must decide if you need to take photographs of your board . If not, buy an old, second-hand PCB microscope for around £150. If a photograph and visual clarity for building projects is important, then this is a great purchase. It's certainly a valuable addition to our lab, and you can expect all future *Pic n' Mix* images of PCBs to come from it!



Using Stepper Motors



Part 5 | by Paul Cooper | technobotsonline.com

Bipolar stepper motor driver modules

In this final part of our mini series on using stepper motors we will focus on the features of commercially available stepper driver modules suitable for home constructor use. The stepper drivers in this article are all manufactured from the US company **pololu.com** and are available in Europe from UK company **Technobotsonline.com**

Before we delve into the more advanced stepper drivers available, we need to be sure we know how to select a hybrid stepper motor, as its characteristics may dictate the stepper driver required.

Hybrid stepper motor characteristics

In part 1, we briefly introduced the basics of choosing a stepper motor in terms of frame size (NEMA), shaft type, holding torque, speed and step size. However, the range of stepper motors available can be quite daunting and their differences may appear subtle. Nevertheless, understanding the features will help in finding the ideal match for your application.

Let's assume, as it is most likely to be the case, each stepper motor you look at has a step angle of 1.8° and microstepping will be used to get the resolution needed. The remaining two vital considerations are holding torque and angular velocity. It's straightforward to work out the angular velocity or rotational speed (RPM) that your project needs, but holding torque is not always so easy to find. Holding torque is certainly of interest for building a steady cam for example, but for applications where torque is needed at high rotational speeds, beware that the torque available from a stepper motor decreases as its rotational speed increases. Table 8 compares the specification for four similarly sized NEMA 17 (42 × 42mm) hybrid motors.

Table 8 highlights variations in motor performance, which is primarily due to the winding conductor size and which in turn relates to the number of turns on the winding. Motors with many turns of fine wire, such as for types 1 and 3 offer a reasonable holding torque (32 to 36 Ncm) for a phase current of 0.4 to 0.8A. However, many turns of fine wire results in a higher inductance; and a higher inductance translates into a lower peak rotational speed. Note how motor type 1 has about half the torque of type 2 at 450 RPM, even though their holding torques are similar. Type 3 cannot even reach 450 RPM; it will stall before it gets to that speed.

If our application needs good torque at high speeds then we need a motor with a low inductance, such as types 2 and 4. Low-inductance motors have fewer turns of larger-gauge winding wire, but this comes at a cost of needing a higher phase current. The resulting lower operating voltage is a benefit in that we can easily overdrive the motor to further counteract the inductance, as described in the previous part of this series. Out of these four motors, you would choose type 4 for applications where you needed high torque at high speed and type 3 where low speed and low operating current were specified.

Specialist suppliers can offer many hundreds of variants of stepper motors for optimum matching, but if your application is not so critical then many other electronics retailers offer a smaller range of motors.

Case study

Recently, I was involved in selecting hybrid motors for a CNC router. The *x* and *y* axes needed to move at 9m/min with a step size of 15μm, but the force needed was uncertain. Theory suggested a suitable NEMA 23 motor specification for the speed, but reality was quite different for the forces involved. It took three attempts to get the right motor specification. Each motor was tested by accelerating the *y*-axis with the gantry restrained by a spring balance on a tether. A point would be reached when the motor stalled and the corresponding maximum force was read off the spring balance. While each motor would work in terms of the 9m/min speed needed, two of the motors failed to provide adequate torque. The third was successful and was adopted for production.

Terminology

In describing stepper motors, we have used some engineering terms that may not be familiar to all readers, so let's expand on a few of the more fundamental terms: torque, hysteresis and angular velocity.

Table 8: Comparison of four NEMA 17 hybrid stepper motors

Type	Motor depth (mm)	Holding torque (Ncm)	Voltage (V)	Phase current (A)	Phase resistance (Ω)	Inductance (mH)	Torque at 450 RPM (Ncm)
1	39	36	5.4	0.85	6.3	10	15
2	40	45	2.2	2	1.1	2.6	28
3	48	32	12	0.4	30	25	Stall
4	48	59	2.4	2	1.2	3	39

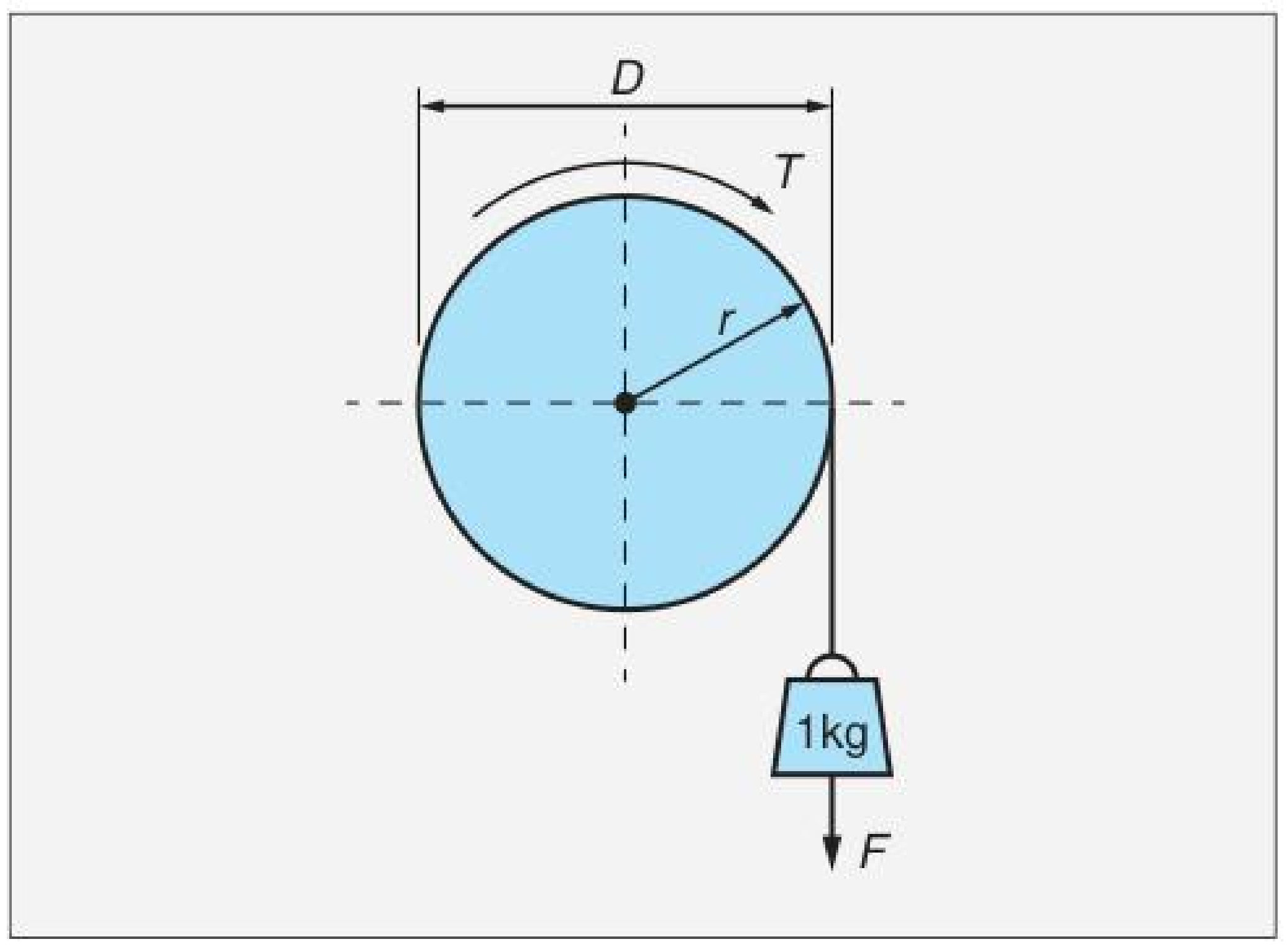


Fig.35. Relationship between torque, force and distance.

Torque

First, torque, which is a turning force that causes rotation around an axis and has the SI unit of newton metres (Nm), although for the size of stepper motors we generally use, newton centimetres (Ncm, where 1Nm = 100Ncm) is more commonly used. A frequently asked question from customers at **Technobotsonline.com** is, 'What size motor do I need to lift a small load?'. (This question equally applies to brushed DC motors as well as stepper motors) This enquiry is often missing any supporting customer data to allow a calculation to take place. Ultimately, it is torque at a particular RPM that we need to derive.

For example, we require a stepper motor fitted with a 50mm-diameter pulley fixed to its shaft to lift a mass of 1kg a distance of 1m in 1s (see Fig.35).

The force F due to the 1kg mass is given by: $F = ma$, where m is the mass and a is the acceleration due to gravity (g, so here, $a = g = 9.8\text{m/s}^2$). Thus, we have: $F = 1 \times 9.8 = 9.8\text{N}$ (newtons).

The torque (T) is the force (F) multiplied by the perpendicular distance from the point where the force acts to the axis of rotation, which for a circular pulley is simply its radius (r), or half its diameter (D). In other words, $T = F \times r = F \times D/2$. For the 50mm (0.05m) diameter pulley, $T = F \times D/2 = 9.8 \times (0.05/2) = 0.245\text{Nm}$ (or 24.5Ncm).

That's fine for the holding torque but we need that torque at a certain RPM to lift the mass in the specified time period.

The pulley circumference (C) is given by: $C = \pi D = 3.14 \times 0.05 = 0.157\text{mm}$. Therefore, we need $1/0.157 = 6.37$ rotations of the pulley in one second or 6.37×60 rotations per minute, which is 382 RPM.

It looks very much like only motor types 2 and 4 in Table 8 will manage the 24.5Ncm at 382 RPM, but there is another important consideration, and that is the acceleration required. The quicker you wish to accelerate the load, the more force and thus more torque required. Even maintaining a constant velocity will require more motor torque.

Let's see what effect this has on the stepper motor torque when we accelerate our 1kg mass to full speed in just 0.05s.

The required acceleration from rest is calculated from: final velocity / time, where final velocity (m/s) = 1m/s and time = 0.05s, giving $1/0.05 = 20\text{m/s}^2$.

The additional force due to accelerating the mass is again $F = ma$, which supplies $1 \times 20 = 20\text{N}$. Adding this additional force of 20N to the steady state force of 24.5N gives 44.5N, and thus a revised torque of $T = 44.5 \times (0.05/2) = 111\text{Ncm}$.

It is now becoming obvious that none of the motors in Table 8 will have sufficient torque to meet this criteria. If the application allows, rather than choose a different motor, reducing the rate of acceleration significantly could allow motor type 4 to be used.

This demonstrates the importance of knowing the forces involved when sizing a stepper motor. The theoretical example above ignores any other losses such as friction, so as with most engineering designs, it would be prudent to add a safety margin to the calculated motor size.

Hysteresis

In the last article we discussed the problem of too small a step size resulting in the motor rotor not responding to a step change due to losses in the motor and the relatively small step change in the magnetic field. Thw result is a positional error caused by the magnetic hysteresis and/or mechanical friction. Put simply, if you push something and it moves, when you release it, does

Table 9: Pololu.com motor stepper motor drivers comparison

Driver chip	Min operating voltage (V)	Max operating voltage (V)	Max continuous current per phase[1] (A)	Peak current per phase[2] (A)	Microstepping down to	Special feature		
A4988	8	35	1	2	1/16			
DRV8825	8.2	45	1.5	2.2	1/32			
DRV8834	2.5	10.8	1.5	2	1/32			
DRV8880	6.5	45	1	1.6	1/16	AutoTune	Digital current control	
MP6500 Pot	4.5	35	1.5	2.5	1/8			
MP6500 Digital				2		Digital current control		
TB67S279 FTG	10	47	1.1	2	1/32	Auto Gain Control		ADMD
TB67S249 FTG	10	47	1.6	4.5	1/32	Auto Gain Control		ADMD
STSPIN 820	7	45	0.9	1.5	1/256			
STSPIN 220	1.8	10	1.1	1.3	1/256			
TB67S279 FTG	10	47	1.2	2	1/32	Auto Gain Control		ADMD
TB67S249 FTG	10	47	1.7	4.5	1/32	Auto Gain Control		ADMD
AMIS-30543	6	30	1.8	3	1/128	SPI interface	Low-EMI PWM	Back EMF fb
TB67S128 FTG	6.5	44	2.1	5	1/128	Auto Gain Control		ADMD
DRV8711	8	50	4	6	1/256	SPI interface	Back EMF feedback	

1. On Pololu carrier board, at room temperature, and without additional cooling.
2. Maximum theoretical current based on components on the board (additional cooling required).

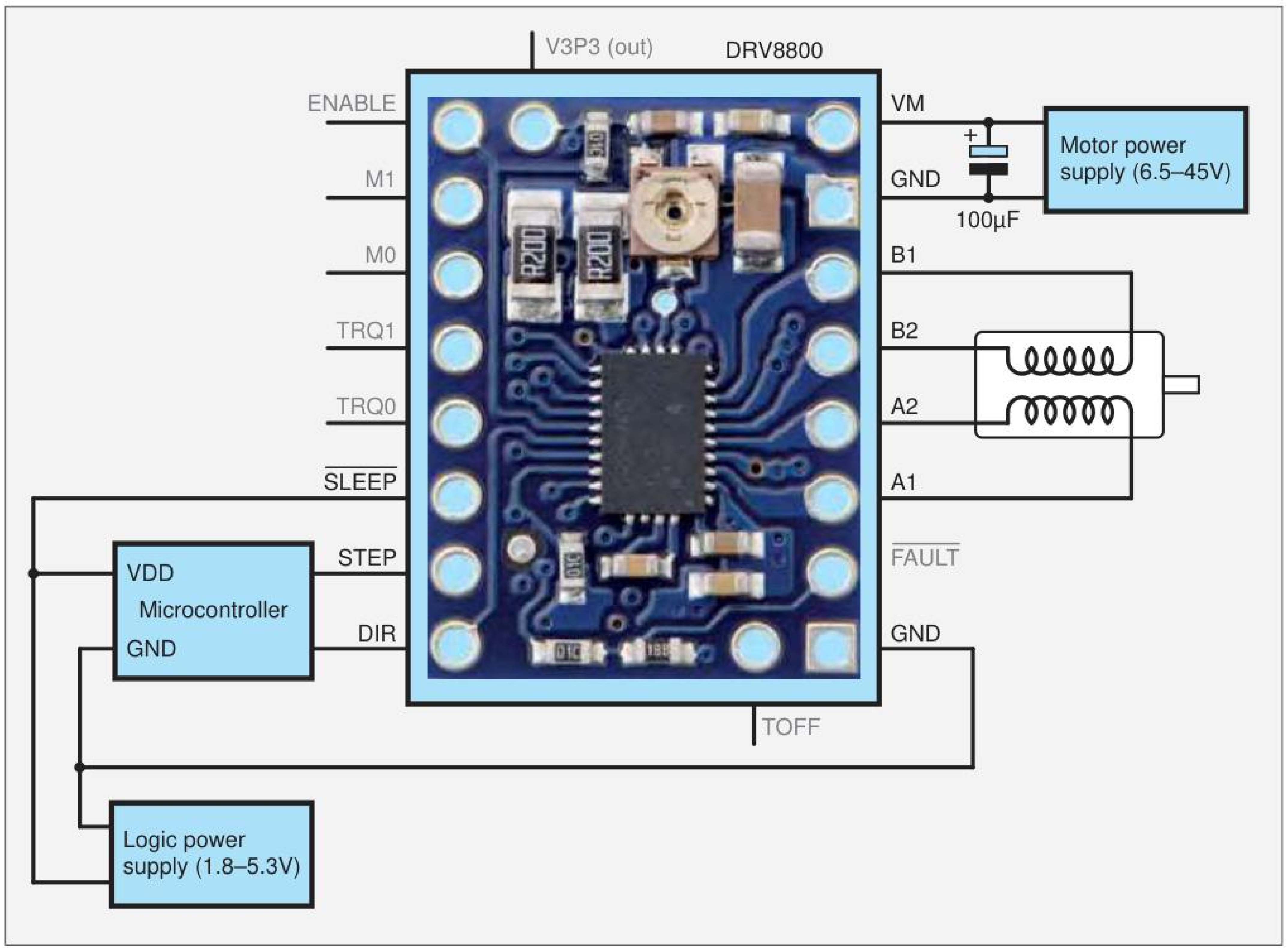


Fig.36. The Texas DVR8880 driver breakout board. (Image courtesy of Pololu.com).

it return to the starting point? If not, it's exhibiting hysteresis.

Angular velocity

Angular velocity is defined as the rate of change of angular position of a rotating body and is measured in angle per unit of time; for example, degrees or radians per second, or revolutions per minute (RPM). While RPM is not really a recognised way of describing angular velocity, RPM and angular velocity are used interchangeably, especially where motors are concerned.

Advanced stepper motor drivers

In the last article, the A4988 driver was described because it offered the basic requirements of a bipolar stepper motor driver in terms of step, direction and microstepping. From this point on, we will differentiate between stepper motor drivers and stepper motor controllers. Drivers like the A4988 interface via their step and direction lines, but generally need a microcontroller for all but the most basic of applications that do not require positional control. Stepper controllers contain a microcontroller on-board, allowing for other means of interfacing that do not necessarily require an external microcontroller.

Table 9 details 15 different stepper motor driver chips that are all available as a **Pololu.com** breakout board ready for use in your project. Some of the differences between the drivers are self-explanatory; minimum and maximum operating voltage and current per phase for example. Let's now look at some of the special features on selected drivers.

DRV8800

Take the DRV8800 (Fig.36) for example. It has some rather nice extra features. The on-board potentiometer sets the maximum current just like on the A4988 from last month, but the digital inputs TRQ1 and TRQ2 can be used to scale the current limit to 25%, 50%, 75% and 100%. This allows you to reduce the winding current when full speed or torque is not required; for example, when the motors are idle.

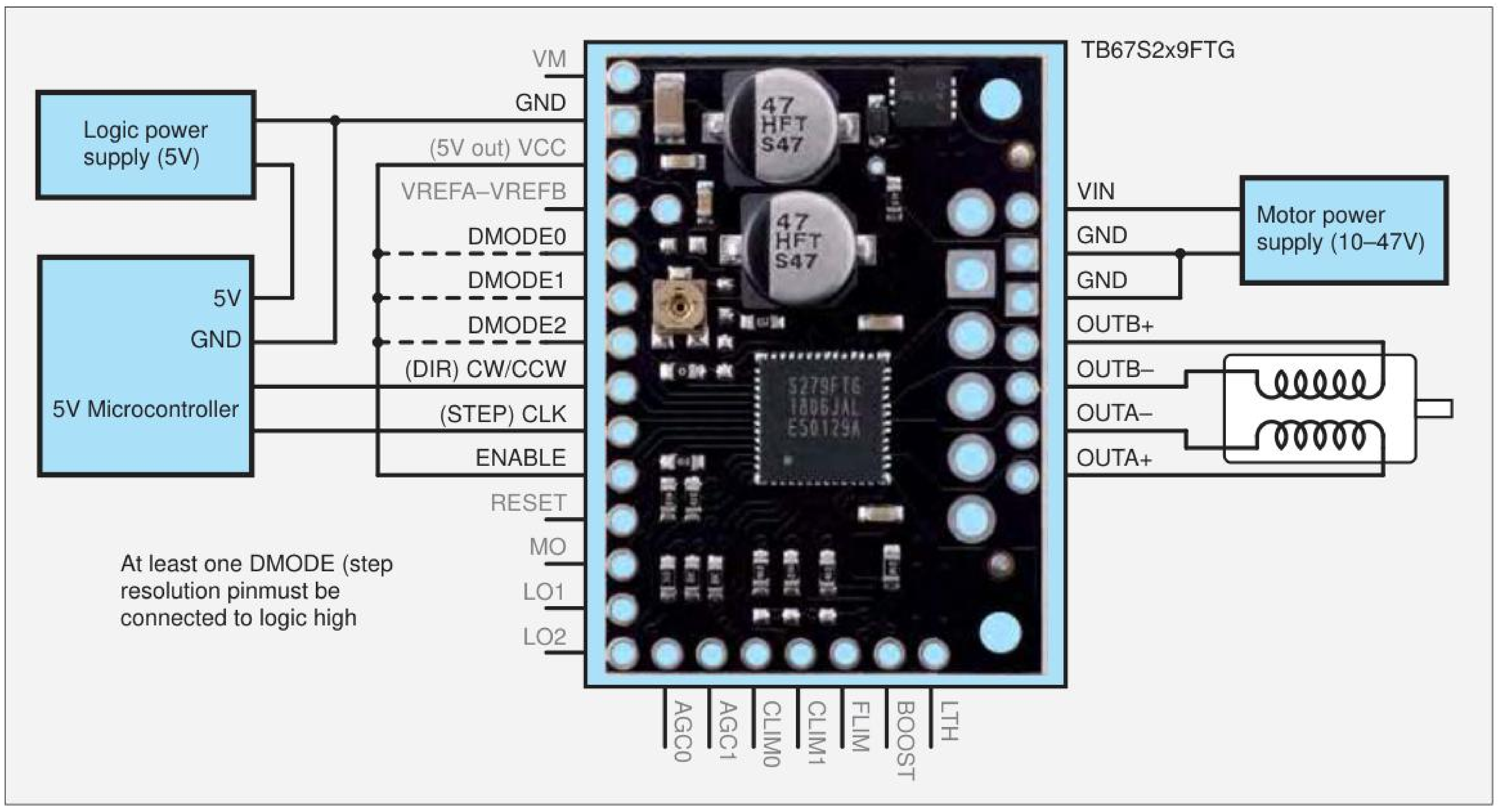
The second new feature to describe is the default mode of 'Autotune' (a trademark of Texas Instruments). Autotune automatically tunes stepper motors for optimal current regulation performance and compensates for motor variation and aging effects. Autotune automatically adjusts the current decay time for the winding current to reduce ripple and switch to a fast decay in order to reach the next step quickly. It is also possible to configure the driver to have fixed slow, fast or mixed decays. Other features include over-temperature thermal shutdown, over-current shutdown, short-circuit protection and under-voltage lockout.

A number of the drivers in Table 9 have auto gain control and ADMD like the TB67S279FTG (Fig.37). ADMD is the term Toshiba use to describe their Advanced Dynamic Mixed Decay architecture. ADMD is similar to the Texas mixed decay described above, although Toshiba claim theirs is able track input currents more closely than 'conventional' mixed-decay modes.

Auto gain control (AGC)

Auto gain control automatically optimises the motor current by sensing the load torque applied to the motor and dynamically reducing the current below the full amount. This allows it to minimise power consumption and heat generation when the motor is lightly loaded, but if the driver senses an increased load, it will quickly ramp the current back up to the full amount to try to prevent a stall. Stepper motors driven at their rated maximum current will most likely run hot, especially when idle, and they may even become be too hot to touch. AGC can help reduce the heat rise in the motor.

Another feature of the Toshiba driver is yet another acronym, ACDS or Advanced Current Detection System. This can monitor the motor winding current without the need for external current-sense resistors. Over-temperature shutdown, over-current detection, motor load open are also standard in the driver chip but additionally, **Pololu.com** has added reverse-voltage protection up to 40V to the breakout board.



At least one DMODE (step resolution pinmust be connected to logic high

Fig.37. The Toshiba TB67S2x9FTG series of driver breakout boards. (Image courtesy of Pololu.com).

AMIS-30543 driver

The AMIS-30543 (Fig.38) is a driver we rather like at **Technobotsonline.com** because compared to others we have tried, motors run cooler and quieter. It does have one significant complication – before it can be used it has to be initialised with an external microcontroller over its SPI bus to set its various operating parameters. Therefore, this controller cannot be used in a standalone application even though it does have step and direction pins; you will need a PIC or Arduino microcontroller.

Pololu.com have provided an Arduino library that takes care of the basic SPI interfacing as well as some of the more advanced features. Setting the current limit, microstepping and enabling the driver over SPI are required before you can use the driver, and these values are not retained when power is cycled. In a forthcoming article we shall be using this driver for a 3-axis CNC controller, so we'll provide a more in-depth explanation of this driver then.

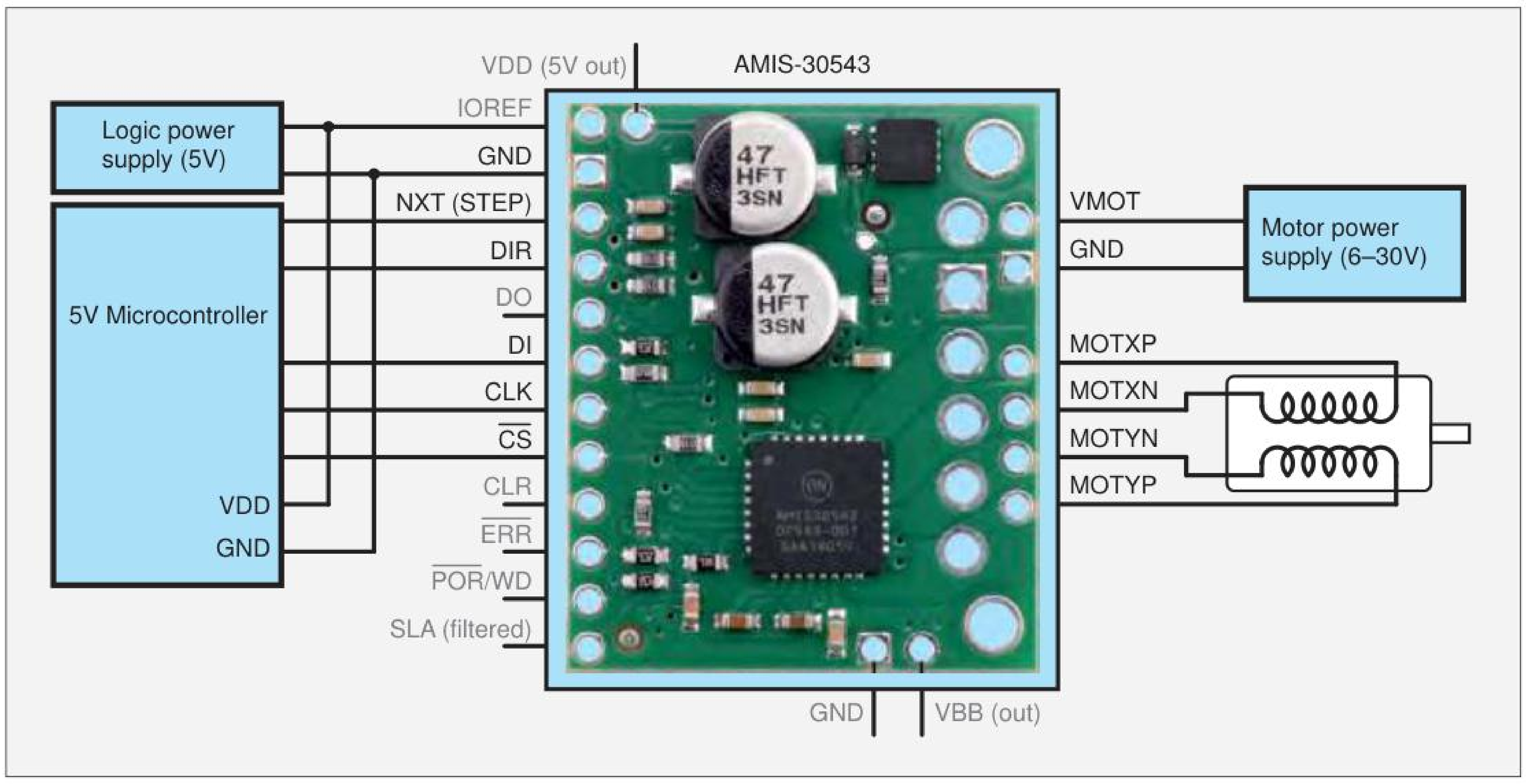


Fig.38. The ON Semiconductor AMIS-30543 driver breakout board. (Image courtesy of Pololu.com).

Features of the AMIS-30543 include thermal warning and shutdown, over-current detection, open-coil warning, charge-pump failure and SLA. SLA (speed / load angle) is an output pin that provides an output voltage that indicates the level of the motor back-EMF (BEMF) voltage. The SLA pin can be used for stall detection or closed-loop control of the torque and speed based on the load angle. This is a more advanced feature, but does give an indication of what is now being included in modern stepper driver chips.

Stepper motor controllers

All of the drivers described so far use the step and direction interface, but it could be useful to have other interface options available for certain applications. The driver chips are very limited in this regard, but with some additional circuitry it is quite possible. **Pololu.com** have a range of stepper controllers, which they call their 'Tic family'. In addition to step/direction control, each of the controllers offers six additional means of interfacing:

- USB (direct connection to a computer)
- TTL serial
- I²C serial for microcontrollers
- RC servo pulses
- Analogue voltage (potentiometer / joystick)
- Quadrature encoder

Many of the settings in the Tic controllers can be configured using a free utility (for Windows, Linux and Mac) which simplifies initial setup and allows for testing and monitoring of the controller using a micro-B USB cable.

Tic T249

One example of these stepper drivers is the Tic T249 (Fig.39) based on a TB67S249FTG, which is a higher-rated version of the TB67S279FTG driver described earlier. Also on the controller breakout board is a PIC18F45K50 microcontroller to take care of the additional interfacing options and new features.

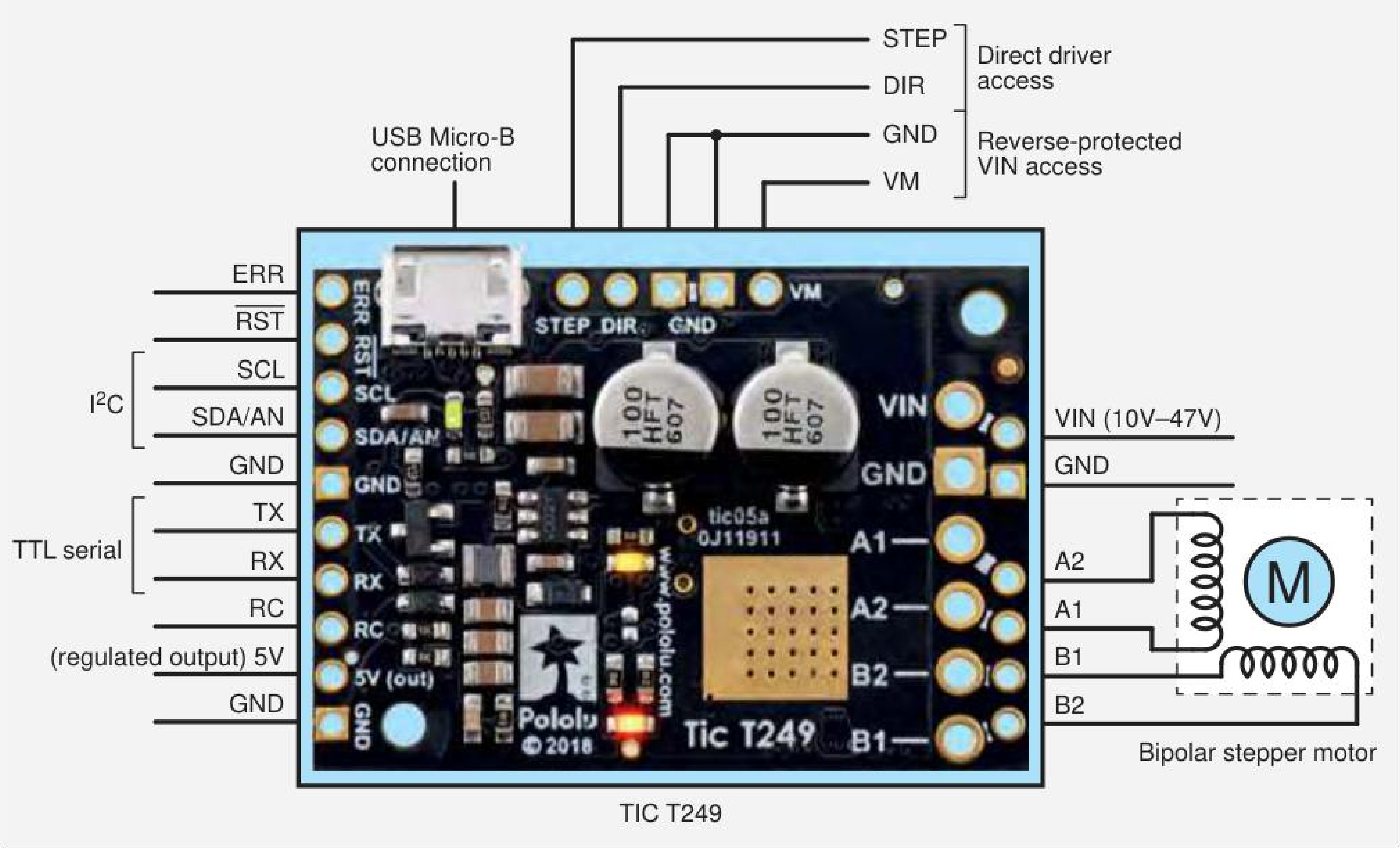


Fig.39. Tic T249 stepper controller. (Image courtesy of Pololu.com)

In addition to the inherent features of the TBS67249FTG, with the Tic T249 you have:

- Adjustable acceleration and deceleration periods
- Maximum stepper speed: 50,000 steps / sec; minimum speed: 1 step / 200 secs
- Digitally adjustable current limit
- Input calibration and adjustable scaling degree for analogue and RC signals
- Optional limit-switch inputs with homing capabilities
- Optional kill switch input

I²C, USB and TTL are beyond the scope of an introductory article, but we hope to cover them later; however, the other three options are certainly worth examining here.

Radio control Servo

Many of us have dabbled with radio control (RC) models and are likely to be familiar with servos connected to the RC receiver. Theses servos use an industry-standard signal with a pulse width in the range of 1-2ms, where 1ms is 100% transmitter stick down, 2ms is 100% stick up and 1.5ms is in the neutral or middle position. Traditionally, this pulse is usually updated every 20ms. Connect your RC receiver to the Tic (Fig.40) and the Tic behaves as though it is a servo. Unlike a traditional servo, there is no positional feedback; it is open loop, although you can use a homing switch input.

Using the configuration utility, you can set the number of steps taken in either direction relative to the RC pulse width.

Another RC mode is available where the Tic acts like an electronic speed controller (ESC) but with a stepper motor rather than a DC motor. This time the RC pulse width relates to the stepper motor speed, where

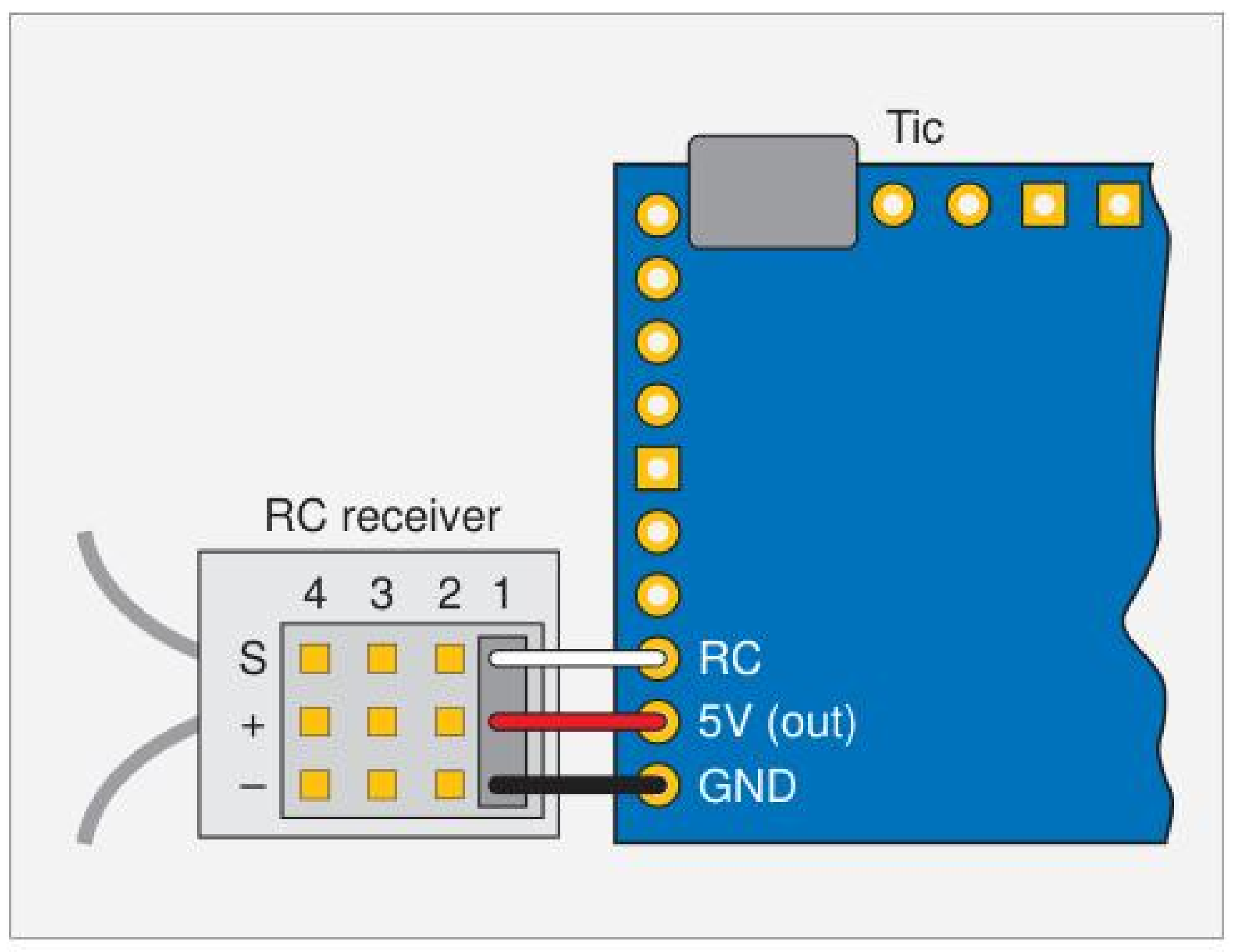


Fig.40. Connecting an RC radio receiver to a Tic controller to act as a servo. (Image courtesy of Pololu.com).

1.5ms is stopped, 1ms is full reverse speed and 2ms is full forward speed.

Analogue voltage

In this mode, instead of the RC pulse input, you can use a voltage or potentiometer (Fig.41) to control the position of the stepper motor or the motor speed, just like the RC option.

Encoder position

Stepper motors are usually driven in open loop, which means there is no physical feedback of its actual angular position (which you would have in closed loop). CNC-type machines will have a home switch, the controller would on request drive until the home position switch is reached, and this would reset the internal counters to its origin position. From there, the controller would keep track of how many steps it moves so it believes it knows where it is. If the motor is stalled or loses steps then you will have a positional error. The trick here is to engineer the system so that the motor is never stalled or driven so quickly that steps are lost. Alternatively, encoders are available in both linear and angle (rotary) varieties to give feedback of mechanical position and hence enable closed-loop control.

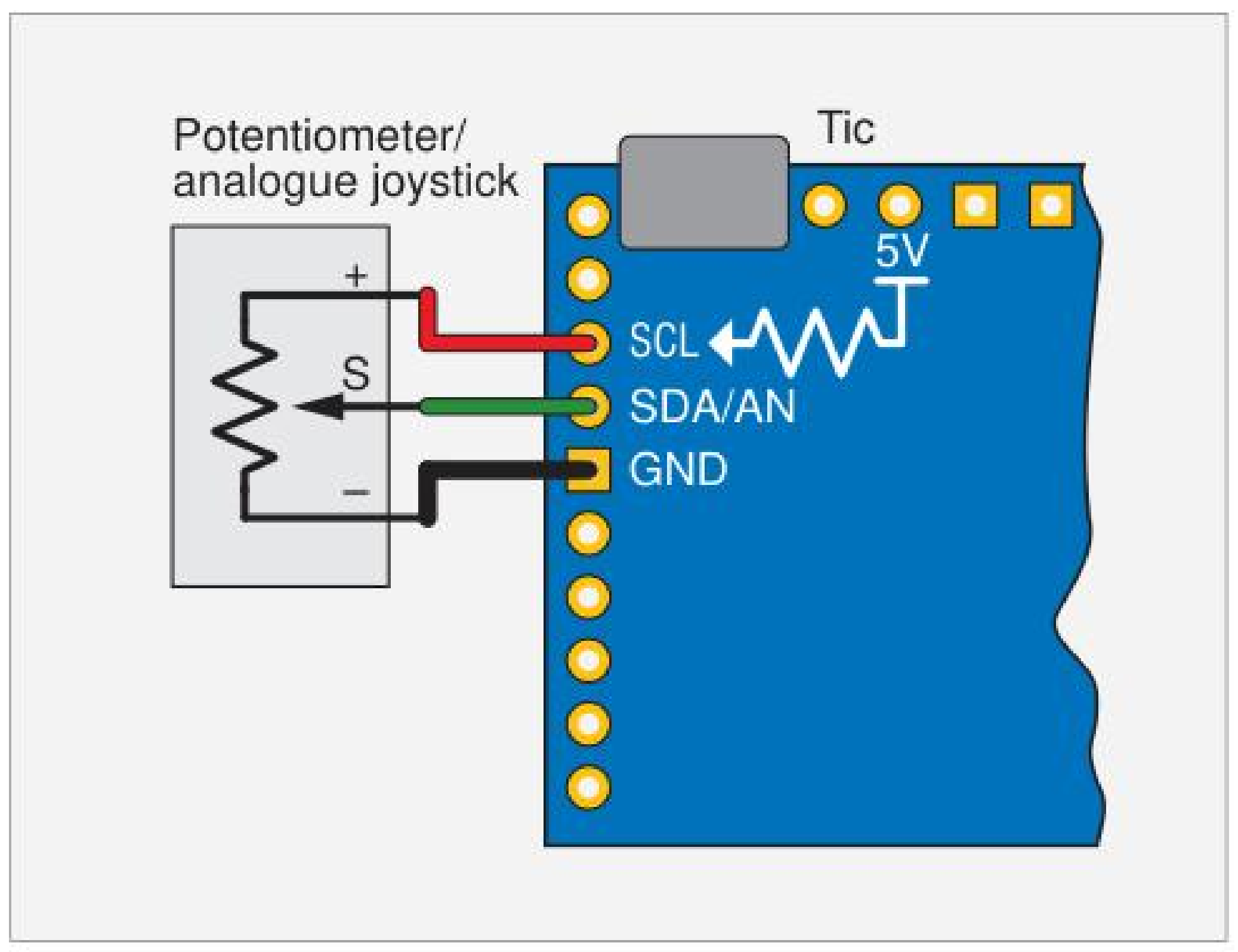


Fig.41. Connecting a potentiometer to the Tic controller. (Image courtesy of Pololu.com).

The Tic T249 is *not* capable of providing closed-loop motor control with encoder feedback but it can use a rotary encoder handwheel (Fig.42); for example this item: **http://bit.ly/pe-feb20-hand**

Like the RC servo and analogue modes, the encoder mode can be set up for either positional or motor speed control.

Over these five articles, we have covered the various types of stepper motors and stepper drivers – from a basic controller you can build with simple components to advanced drivers and controllers. I hope some of the mysteries surrounding the use of stepper motors have now gone and you are already looking at how you can incorporate steppers into your next project. We shall be covering the build of a 3-axis CNC controller next, producing a system that is ideal for making a desktop router or similar.

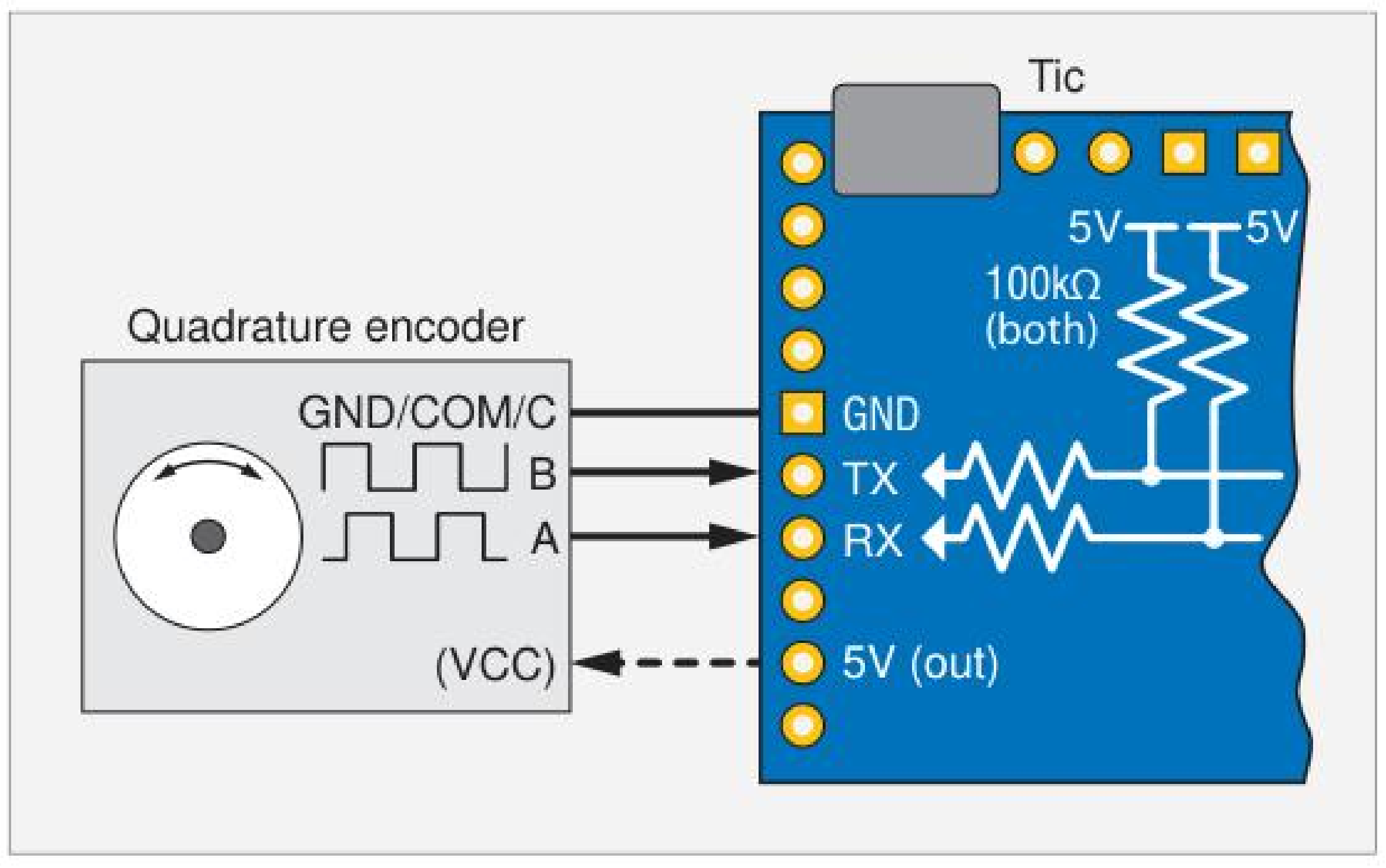


Fig.42. Connecting a quadrature encoder to a Tic controller. (Image courtesy of Pololu.com).

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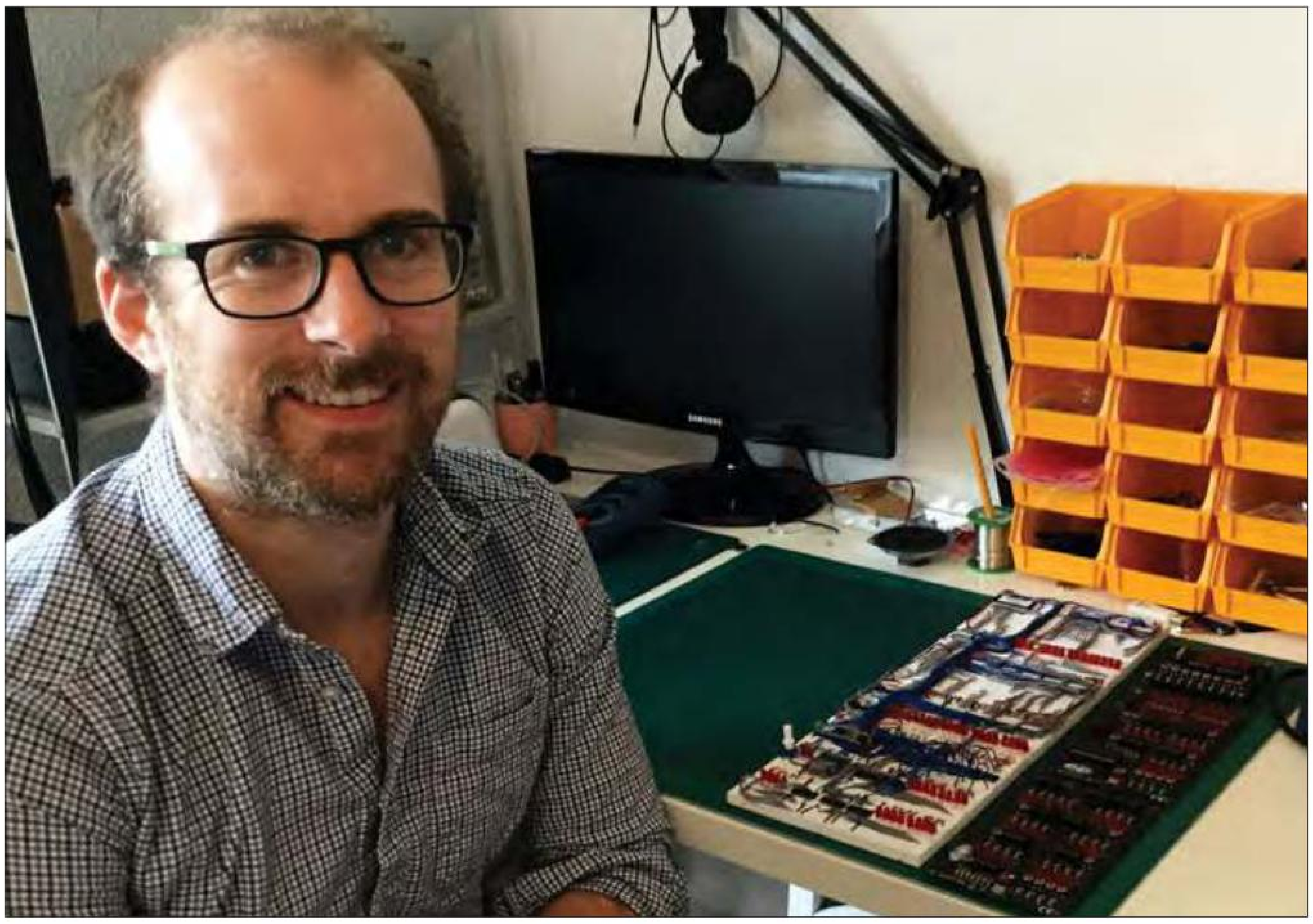

Fig.1. Richard Grafton flaunting a cheesy smile to go with his breadboard computer.

Here's a quote close to my heart: "Three categories of people exist in the world; 'the wanters', 'the wishers', and 'the makers'." (*101 Keys to Everyday Passion* by Israelmore Ayivor, see: **https://amzn.to/2R2JfGq**).

I've been making things for as long as I can remember. Some of them even worked. I only wish we'd had the Internet or someone to mentor me when I was a kid; my dear old dad was hard pushed to replace a fuse. One Christmas, when I was about 10 years old, my parents gave me one of those electronics kits that involved a lot of springs – a simpler version of the 'Electronic Playground and Learning Center' I just found on Amazon (**https://amzn.to/2QVxLEM**). It also came with a book that talked about things like 'resistor bridges,' which made no sense whatsoever to my uninformed brain. Lacking someone to guide me, I'm surprised I survived the experience.

By the time I was 12, my parents had taken out subscriptions to *Practical Electronics* and *Practical Wireless* magazines. I hoarded my pocket money (allowance), and at the beginning of each month I'd keep popping into the newsagent at the bottom of the road on the way home from school to see if either of these magazines had arrived. As soon as I had one in my sweaty hands, I would sit on the wall outside the newsagents reading it. If there was a simple project (typically something that made a lot of noise) that looked interesting and was within my budget, I'd hop on a bus and go to a dingy backstreet electronics components store called Bardwells (**http://bit.ly/pe-feb20-bdwls**), purchase all of the bits and pieces, then return home and disappear into my bedroom for a few hours until – eventually – strange and annoying sounds would ensue.

A lot of my friends at that time made 'stuff.' I thought making things was a common practice. The 1970s were the heyday of the Heathkit when it was cheaper to build something than to buy it, and there were little TV and Radio repair shops all over the place. Then things started to change. It became cheaper to buy things than to build them, and easier to replace something than to fix it. Companies making electronic kits started to close down, DIY magazines started to disappear from the newsagent's shelves, and people in general seemed to lose interest in making things.

I was sad. I thought I was all alone. A little tear rolled down my cheek. I tried to be brave.

Then, suddenly, circa 2005, with a fanfare of metaphorical trumpets (you don't see those everyday), the Arduino was announced, *MAKE* magazine was launched, and the Maker Movement was born. These days it's hard to swing a stick without hitting a maker (not that this is a practice I advocate, you understand).

Now I have friends (one day I'll tell them). One of the great things about what I do – freelance technical consulting and writing – is that I get to meet a lot of interesting folks, including magnificent makers. In my previous column I introduced you to the aptly named Nick Bild in the US. In this column, I'd like you to say 'Hello' to Richard Grafton in the UK (Fig.1.). The following is in Richard's own words.

Say hi to Richard Grafton

I suppose I've been a 'maker' all my life. I remember from a very early age inventing things that popped into my imagination – usually with Lego Technic or anything around the house I could get my hands on. At around the age of 14, I recall finding a book introducing Visual Basic 5 (complete with the software on CD). My curiosity got the better of me; I fired up Windows 95 and started playing with it. Somehow, I intuitively understood what it was all about, and realised I could actually 'make' stuff using a computer.

Of course, this opened up a whole world of exciting possibilities. My crowning glory was writing a (pretty crude) encrypted messaging program which I distributed to my school friends on floppy disks (marked 'Maths Homework') so we could chat over the school's computer network without being detected. It worked pretty well too! I suppose this was when I got excited about making stuff that other people could use.

All this fun culminated in me doing an interdisciplinary informatics and engineering degree at the University of Sussex (which I loved from beginning to end). At the time, I was often surprised to find out that I already knew parts of the computing curriculum because I'd already self-discovered the algorithm or design principle through my Visual Basic tinkering – I just hadn't considered at 14 that there'd already be names for these things or that I'd have to rehash my early software discoveries later on in life to pass exams!

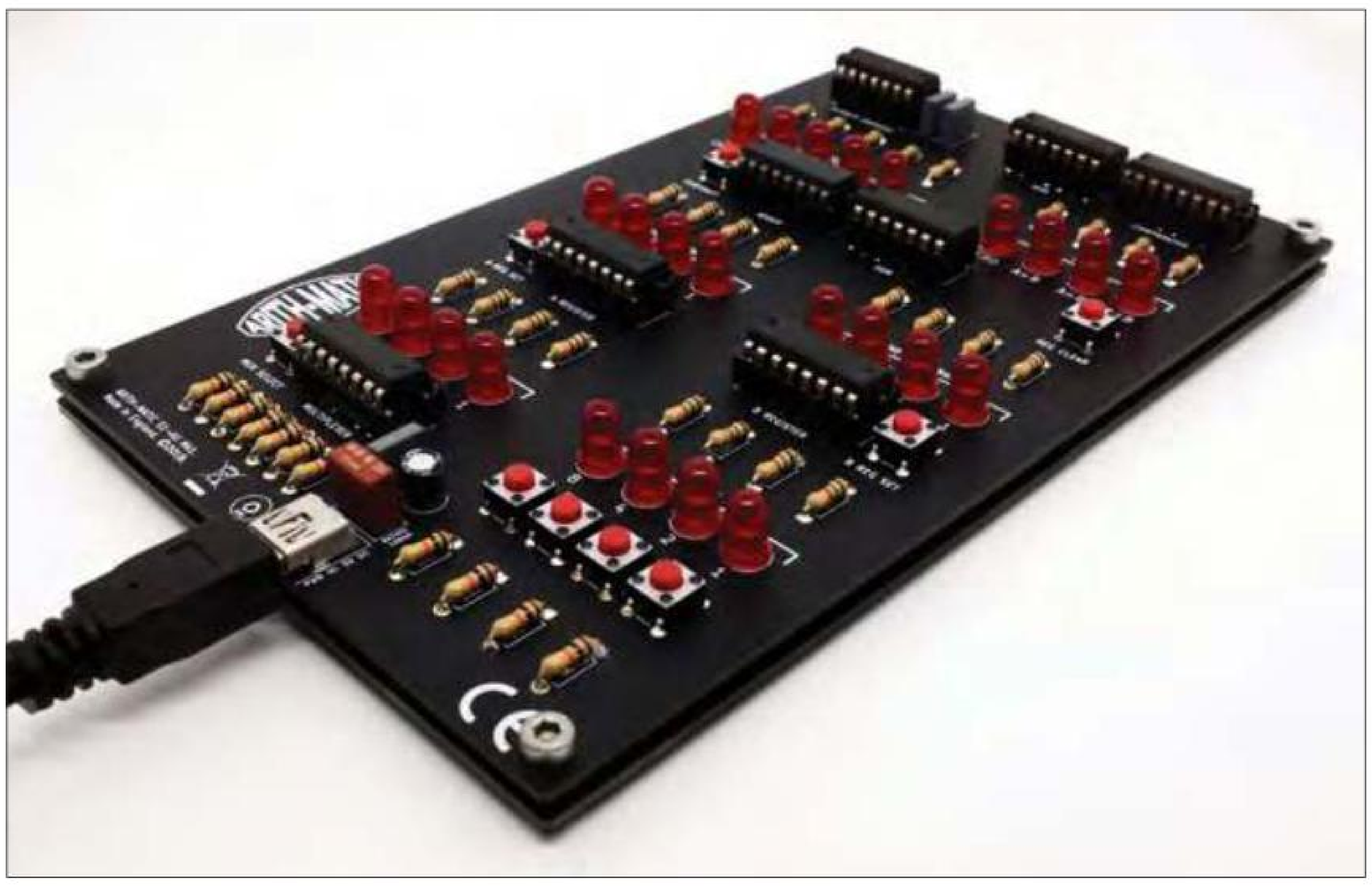

Fig.2. The S1-AU Mk1 4-bit arithmetic unit.

After my time at Sussex, I decided to go into research so I could continue making stuff. I then spent two years training at BBC R&D (learning how to do all this engineering stuff properly). It was a real privilege to be surrounded by so many talented people; also, being able to design things that could make a huge impact really set my life in motion as a technologist before moving into more senior roles in the tech industry.

Now, more than 20 years on from that fateful encounter with Visual Basic 5, I'm still doing exactly what I was doing at 14 – thinking about how I can make something and then willing it into existence. I blame it all on that Visual Basic book, which is still sitting on my bookshelf.

More recently, however, I've begun to explore the world beyond software, and my inspiration for making things has turned towards what has been, rather than what is yet to come.

I think this is important, because software as a medium is always a losing battle against entropy – as soon as you write something it exists for a fleeting moment before it starts its enviable decay towards obsolescence. As a reaction to this, I've started to take more of an interest in hardware, as it seems to have a longer shelf life. But, most importantly, I've rediscovered the physical beauty of hardware, and – to me – the more (seemingly) archaic the better!

Recently, I've found myself becoming increasingly interested in early(ish) computing machines and hardware such as the PDP-8. This is not only because it's beautiful, but because you can actually see what's going on – the computing isn't hidden away on a piece of silicon or in the compiler.

This idea is exciting to me as a maker because it has reopened a whole new world and reignited my imagination for creating – leading to the genesis of my ARITH-MATIC project.

ARITH-MATIC

The story starts back in 2016 when I decided to make a serendipitous trip to the brilliant Museum of Computing in Swindon. This is a rather odd place, hidden away in an unassuming precinct in the town centre, packed full of vintage and retro computing devices from mechanical calculators to early personal computers and classic gaming consoles. I love it.

After wandering around for a few hours, I was struck by two things: the aesthetic beauty of early mechanical calculators and the DIY spirit of the early micro-computer hobbyist kits – especially the Acorn System 1 (1979) and the Science of Cambridge Mk14 (1977). You can call it nostalgia, but there is something I love about these computational devices – how basic and tactile they are, unlike the shiny and polished devices we all carry in our pockets today.

Inspired by the pioneering spirit of DIY electronics and the aesthetic beauty of mechanical calculators, I decided to design my own computational device. This would not only capture the archaic beauty of vintage computing, but also dissect the computational mechanisms that operate at the heart of these machines.

This seed of inspiration is how I ended up tinkering away on a kitchen table late into the evening over a period of several weeks. What emerged was a humble 4-bit arithmetic unit designed using 7400 series integrated circuits – you can think of it as a simple binary calculator. This was the embryo of the first ARITH-MATIC product: the S1-AU Mk1 (Fig.2.).

As a self-confessed geek this was all great fun for me, but according to my partner it was not sustainable to hog the kitchen table! To avoid any inevitable conflict, I moved the project into a shared studio space and slowly developed a series of prototypes. After quite a few redesigns and failures, what emerged were three DIY electronic kits that dissect the complex mechanisms of computation.

I had learnt so much over this period of time and undertaken so much R&D that I realised this

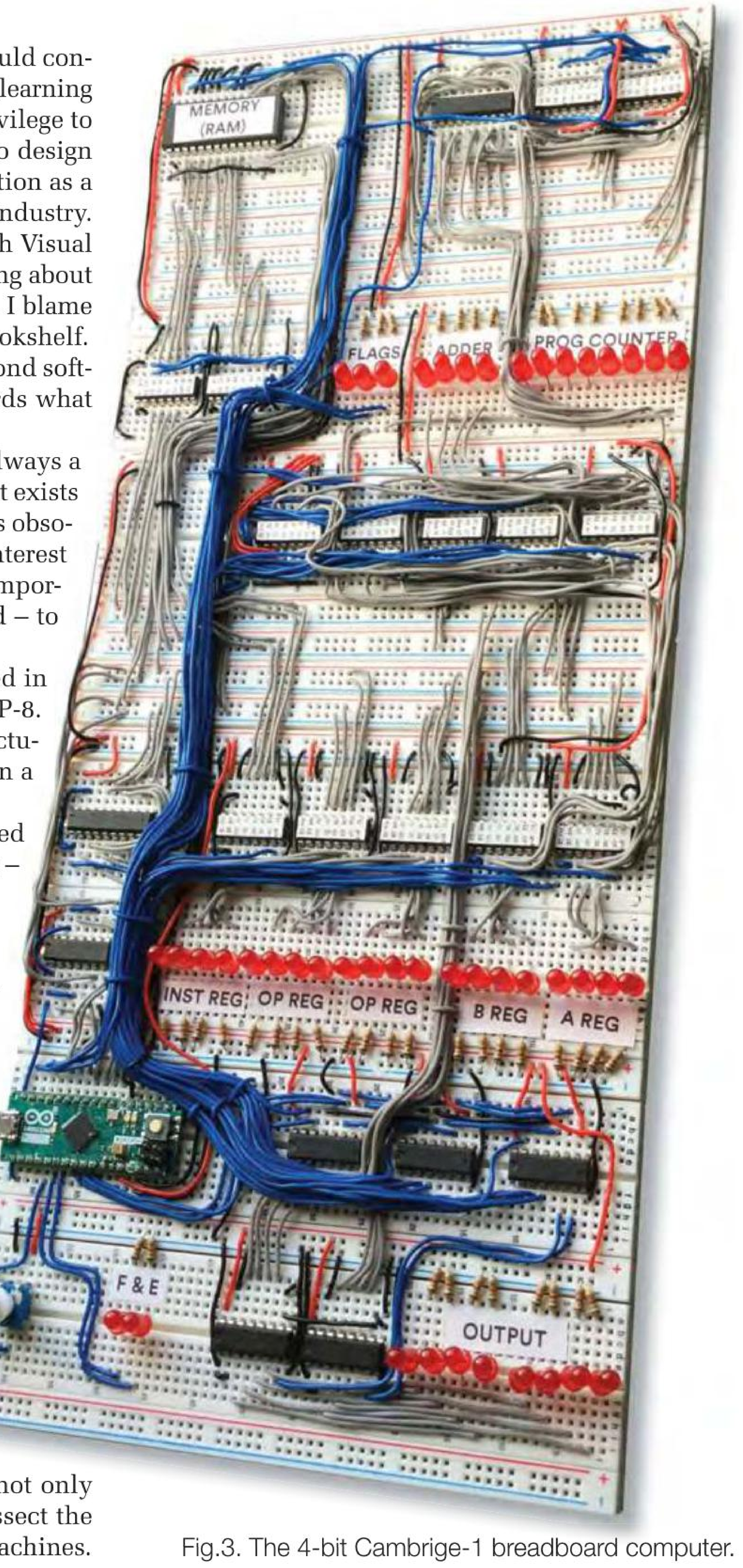

Fig.3. The 4-bit Cambrige-1 breadboard computer.

wasn't really a personal project anymore. I'd taught myself new EDA (electronic design automation) tools, built relationships with PCB manufacturers, opened accounts with electronic component suppliers, captured user-centred feedback from other makers and design engineers, grown a trusted network of freelance support, registered a domain name and was working from a studio. Whether I liked it or not I was actually a micro startup!

At this point things got serious – I was ready to launch. This part, of course, is a whole other story in itself, but I'm pleased to say that – since that time – the S1-AU has found its way into the hands of many more individuals than I could have ever imagined. Enabling pragmatic makers, hobbyists, and enthusiasts to explore the guts of computing in a hands-on and practical way. And, that's a really exciting prospect for a project that started life on a kitchen table.

Back to me (Max)

OK, back to me – Max – again. I have to say that I love the aesthetics of Richard's work in the form of his black circuit boards combined with red LEDs and red tactile momentary pushbutton switches. I also appreciate the way he aligns all of his resistors the same way round, which is just the way I would do it (can you spell 'obsessive compulsive'?). You can discover more about Richard's kits at: **https://arith-matic.com/**

As I mentioned in my *Cool Beans* column in August 2019, I bounce back to England a couple of times a year to visit my dear old mom. On the last Friday before I return to America, a gaggle (an appropriate word to use as a collective noun in this case, I think) of my techno-geek chums travel from around the country to congregate at my brother's house. We spend the day showing off our latest and greatest creations while my mother provides appropriate 'Ooh' and 'Aah' sound effects, as and when required.

Well, on my next visit, Richard has promised to join our merry throng. In addition to his temptingly tasty ARITH-MATIC boards, I'm hoping he will also dazzle us with his 4-bit breadboard computer, which he calls the Cambrige-1 (Fig.3.)

As Richard says: 'The Cambridge-1 is a 4-bit 7400-series-based CPU that features a 4-bit word size, blinkenlights-a-plenty, and some (slightly naughty) Arduino-based cheating to virtualise the control unit. It also contains an 8-bit data and address bus with some instruction set tricks to perform 8-bit operations as well. All of this at a whopping clock speed of 40Hz.'

Richard designed and built the Cambridge-1 to take to the 2019 Retro Computer Festival (**http://bit.ly/34r1SYN**), which was held the Museum of Computing in Cambridge. You can see a video of this little rascal running (the Cambridge-1, not Richard) on YouTube (**http://bit.ly/2OT2FuG**). Also, you can read more about its creation on Richard's website (**http://bit.ly/34trxjA**), and you can delve into the nitty-gritty details on Richard's GitHub page (**http://bit.ly/2OPU4cl**).

Well, that's it for this *Cool Beans* column. I have so much to say, but I can almost feel the editor leaning over my shoulder and saying, 'How many words?'. The problem is that, much like my dear old mum, the real trick is to get me to *stop* waffling. And so, until next time, have a good one!

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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AUDIO OUT

By Jake Rothman

PE Mini-monitor crossover for Wavecor drivers – Part 1

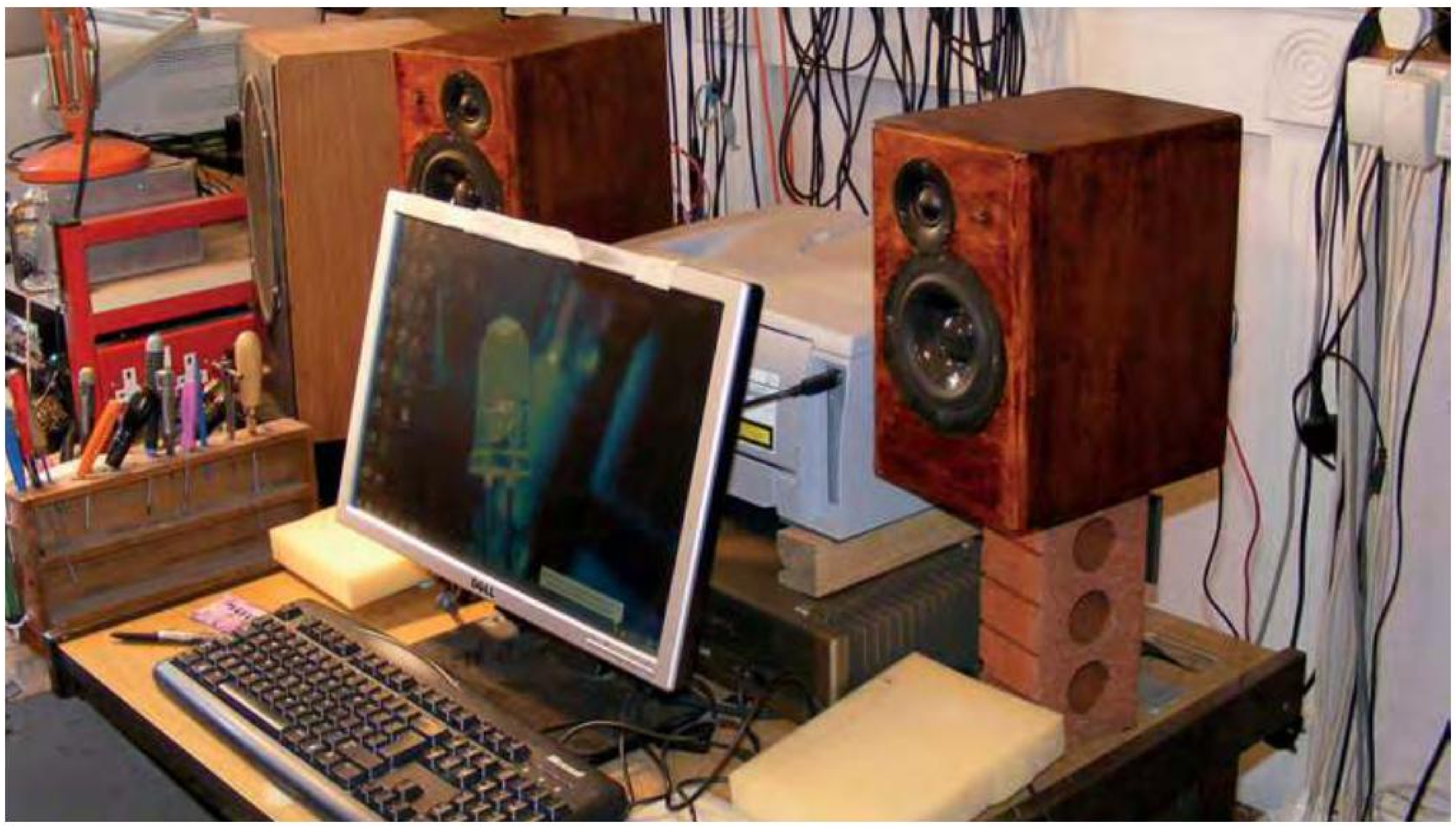


Fig.1. The *PE Mini-monitor* can be used for near-field listening. (Yes, the 'speaker stands' are house bricks!)

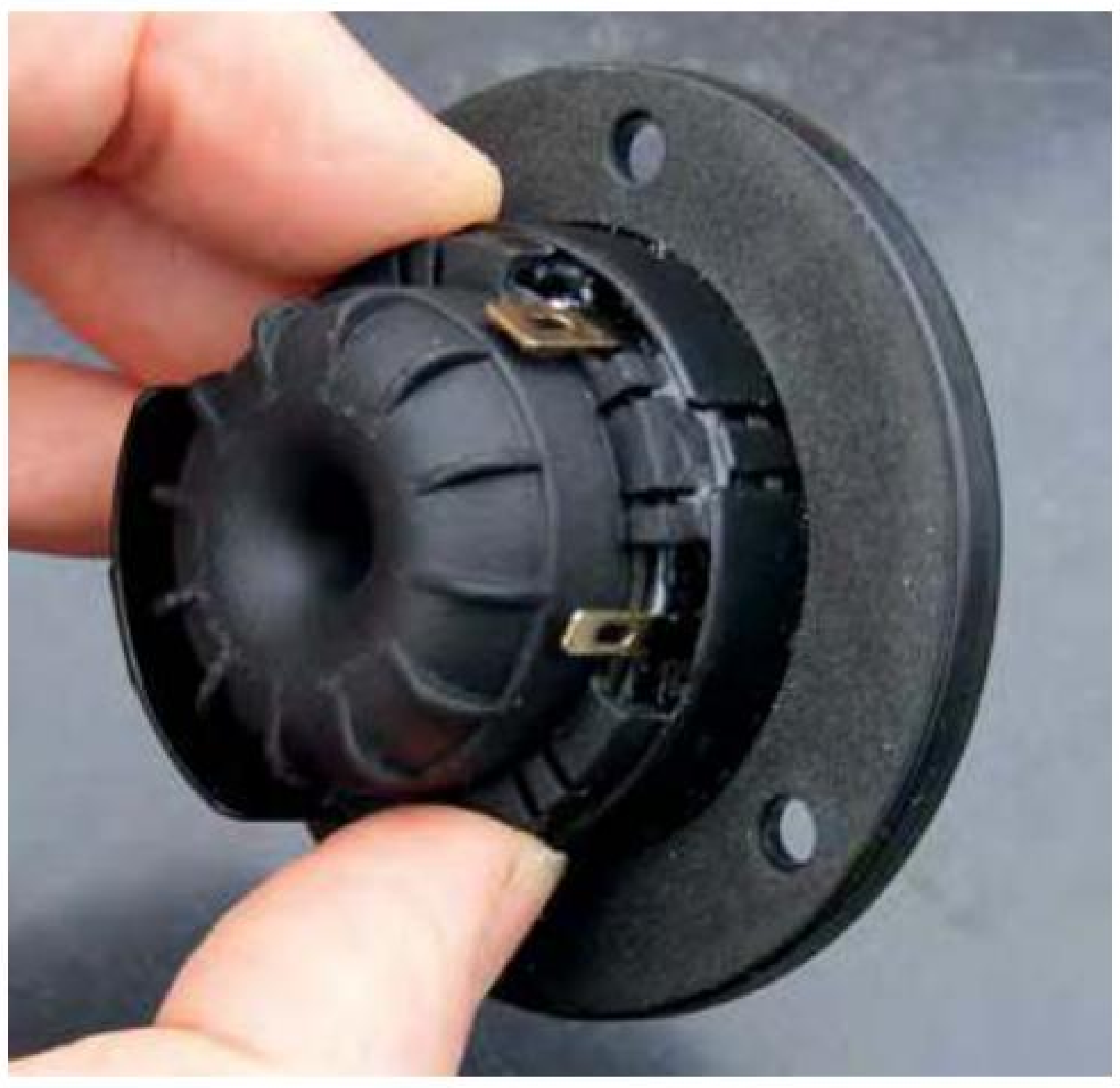


Fig.2. The Wavecor TW022WA04 tweeter is small thanks to its rare-earth ring magnet.

The LS3/5A is arguably the best mini-monitor speaker, but it is very expensive and getting the parts can be tricky. Having spent years trying to get a sound quality as close as possible to the LS3/5A, we present the *PE Mini-monitor*. All speakers are quite imperfect and it has been said you have to fiddle with the crossover for many iterations until the required 'timbrel soup' is obtained – however, the basic technical parameters have to be right first.

Getting parts for speakers is always a problem, so the drivers, crossover PCBs, inductors, capacitors and even enclosure kits will all be available from the *PE* shop. This small speaker is designed for maximum accuracy for its size, so maximum volume is necessarily limited. Its low efficiency of around 80dB/W at 1m will mean an amplifier of minimum 25W RMS into 8Ω is required. The speaker will overload with amplifiers above 60W. The *MX50* amplifier described in *EPE* May 2017 is ideal, but I will be offering even better solutions!

Using the Universal Passive Crossover PCB

The *PE Mini-Monitor* crossover is built on the *Universal Passive Crossover* PCB described last month. Component numbers here refer to those on the general circuit diagram (Fig.9, *PE*, January 2019). This means some component numbers which are not being used will be omitted; for example, C1.

Finding the drivers

The crossover design cannot be started until the drivers have been selected, which means perusing many data-sheets. The B110A is thought by many to be the best small bass driver, even after 40 years, since speaker technology has moved slowly. There have been several contenders on the market, but all too often they have been deleted just as I have completed a design. After getting many samples, I found the Chinese manufacturer Wavecor to be nearest in bass quality with some modern technological improvements along with proven continuity of supply. The tweeters are also good, using small neodymium magnets rather than the large ferrite ring used in the T27, so one of these was also selected.

Selection of crossover frequency

Many *PE* constructors will be wedded to their computers, so it was thought the ideal mini-monitor should be useable either side of a video display (near-field) on a desk, as well as the optimum free-standing arrangement. Most two-way speakers are 'phasey' sounding (disjointed – the tweeter and woofer sound as though they are separate sources) when listened to close-up; often a minimum distance of say 1.5m is needed to get the outputs of the woofer and tweeter to integrate properly. With this design, the drivers are small and mounted as close together as possible. If a relatively low crossover point is used the acoustic centres of the drive units can be less than a wavelength apart. This prevents the lack of integration close-up. A typical computer desk set-up is shown in Fig.1.

Normally, with a 120mm woofer and a 19mm tweeter, a crossover from 3 to 4kHz would be used. In this design a crossover around 2.5kHz was the target. Since the frame of the tweeter is only 65mm diameter, the vertical distance between the drivers centres is just 94mm if their frames are almost touching. The wavelength of 2.5kHz is 138mm (speed of sound (343m/s) divided by frequency) is significantly longer, so a coherent wavefront should be obtained.

Resonant frequency

Most 19mm tweeters have a high resonant frequency of around 1.2 to 1.8kHz, which means they cannot handle a 2.5kHz crossover. A 25mm tweeter would be fine, but then the dispersion at high frequencies would be inferior to the T27. I found Wavecor had the ideal compromise tweeter

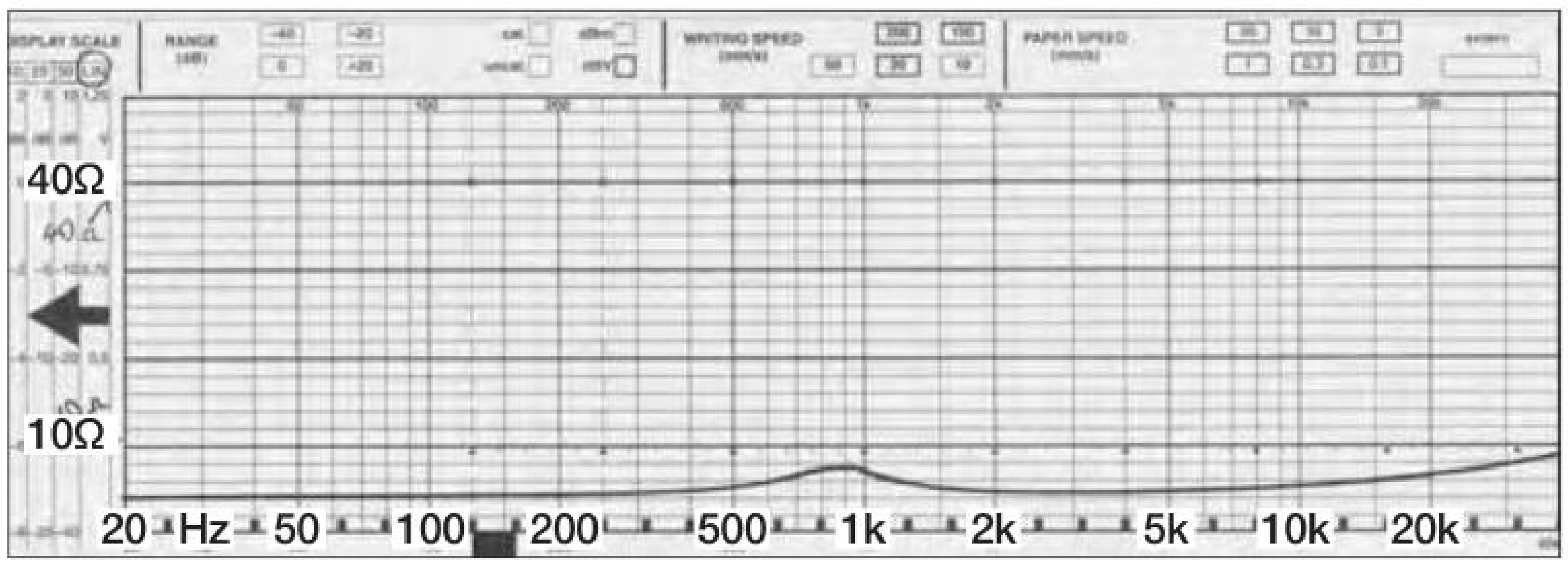


Fig.3. Impedance curve of the Wavecor TW022WA04 tweeter. The 'hump' shows the resonant frequency. Note that the vertical scale is linear and measures ohms (2Ω /div).

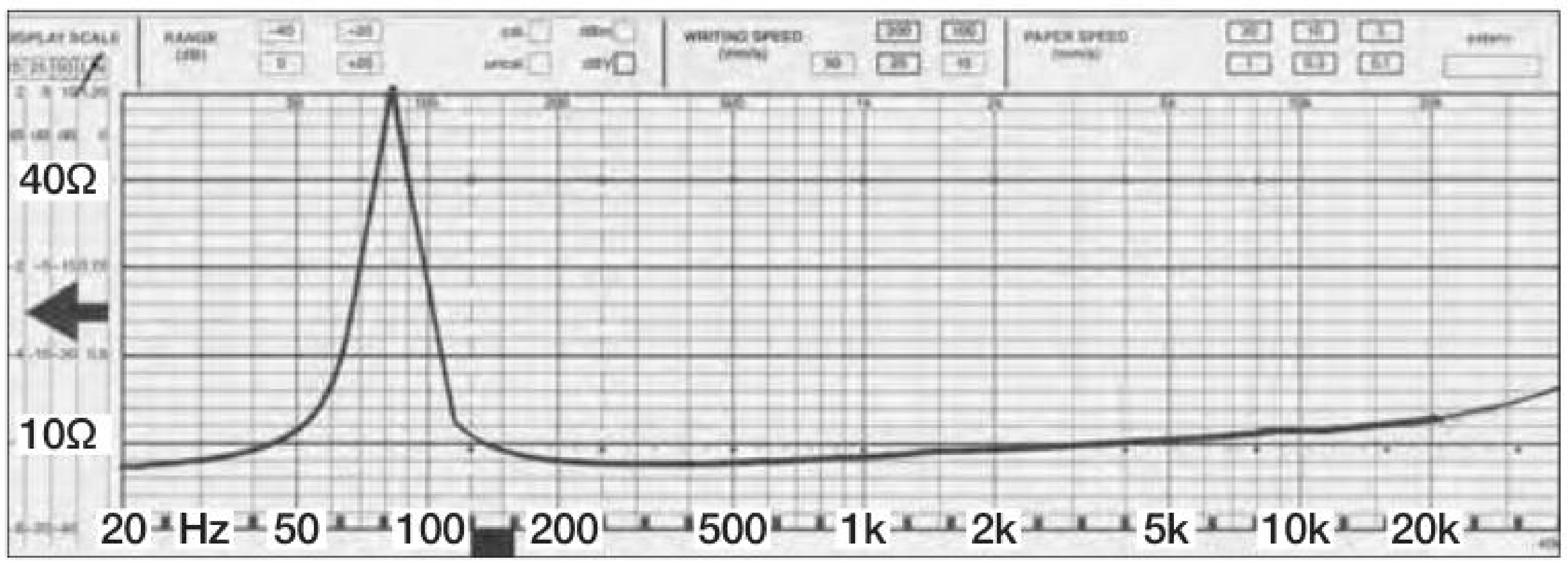


Fig.4. Impedance curve of the Wavecor WF120BD06 woofer. The resonant frequency has been raised by the air-cushion effect of a five litre sealed-box (shown in Fig.1). The inductive rise at high frequencies is much less than normal.

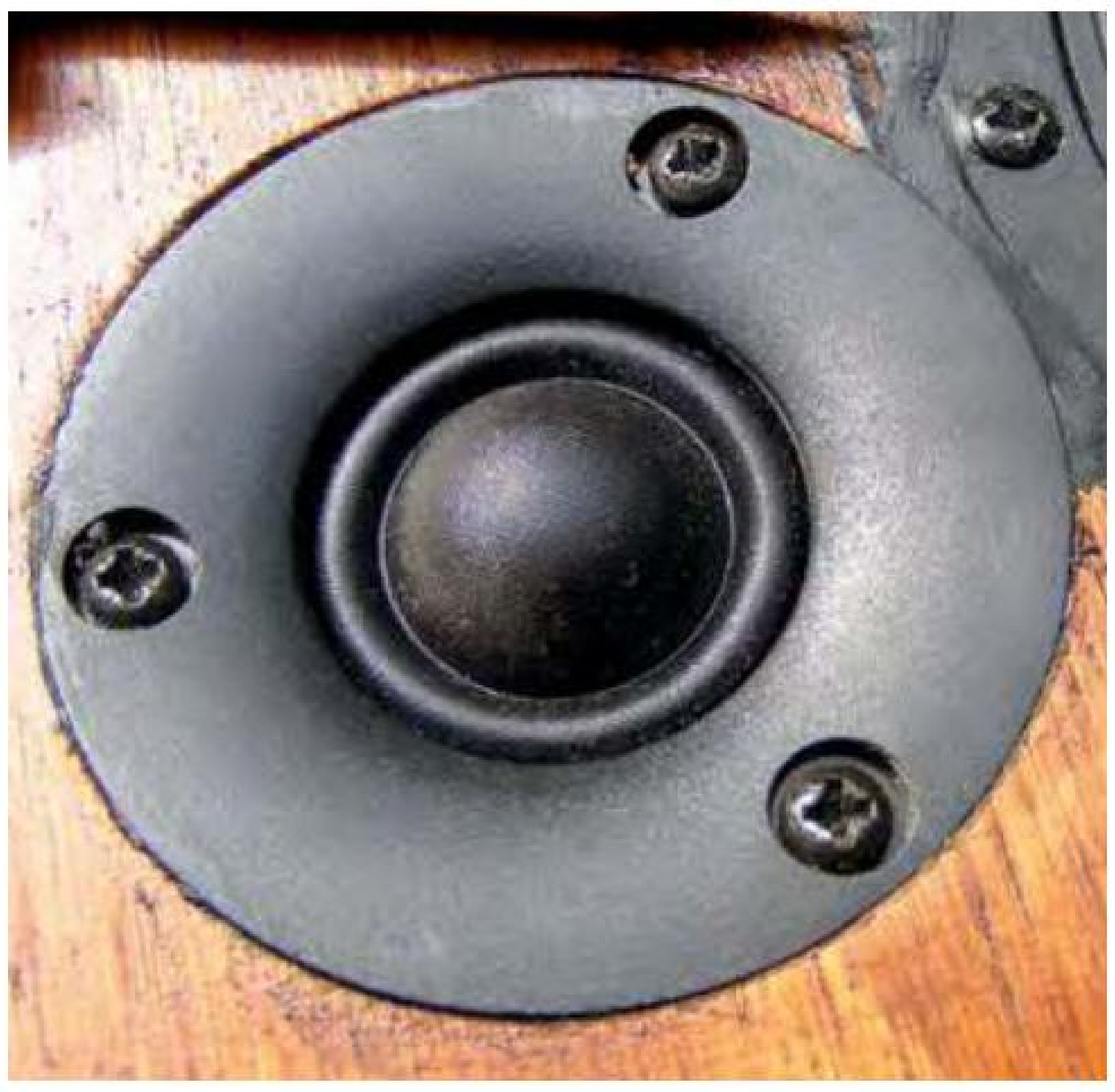


Fig.5. PE Mini-monitor's Wavecor TW022WA04 Tweeter, flush mounted.

– a 22mm unit with a resonant frequency of 800Hz, designated the 'TW022WA04', as shown in Fig.2. It is always worthwhile plotting the impedance curves of any drivers of interest, since they show the resonant frequency clearly as a hump. They can also reveal break-up glitches, damping and inductance. The tweeter curve is shown in Fig.3, revealing a resonance of 850Hz. Note that this tweeter is only available in 4Ω, possibly to keep the coil light, which could cause crossover design problems. Luckily, it's more sensitive than the woofer, so a series resistance can be used to prevent the overall system impedance going below 8Ω. Fig.4 shows the woofer curve with a 5-litre box, giving an 82Hz resonance with high Q. Note that resonant frequencies generally drop 5% as the speaker is used, akin to 'running-in'.

Bass unit

The hardest thing to replicate about the B110A is its high compliance of 3mm/N and its low 37Hz resonant frequency. The Wavecor WF120BD06 4.75-inch unit was higher in both these respects (1.5mm/N and 50Hz). Its high total-driver-system 'quality' or 'peakiness' of resonance, Q_{ts} of 0.4, and its smaller diaphragm diameter (100mm as opposed to the B110A's 115mm) enabled a bass performance only slightly inferior to that obtained in the same box volume as the LS3/5A. The smaller cone area means the free-air resonance is raised less by the 'air-spring' from the confined air in the enclosure. This unit can work well in anything from about 4 litres to 9 litres internal volume. The resonant frequency will vary from 100 to 71Hz (total system *Q* of the of the box = Q_{tc} = 1 to 0.6) so the LS3/5A standard and *PE* 9-inch-deep LS3/5A boxes are ideal. A little bass lift from the amplifier tone controls also helps at low volumes. With the large box it is possible to install a 4-inch by 1.4-inch reflex duct to give an option with more (but worse quality) bass, for those who like electronic dance music. I initially worked out the enclosure figures from a free on-line box-calculator program: **http://bit.ly/pe-feb20-ao1**

I did look at the Wavecor 5.5-inch and 5.75-inch drivers, but their higher 57Hz resonance and larger cone areas would mean a bigger box would be needed. The bass drivers are available with paper or paper/glass fibre-mix cones. I prefer the glass-fibre one because its slightly higher moving mass gives a lower resonant frequency. Wavecor provide PDF data-sheets for both drivers, available on the Wavecor website (**http://bit.ly/pe-feb20-ao2** and **http://bit.ly/pe-feb20-ao3**) and also for download on the February 2020 page of the *PE* website. Fig.5, Fig.6 and Fig.7 show the drivers in question.

Pumping iron

The motor system of the Wavecor unit is better than the B110A, which helps compensate for the smaller and stiffer diaphragm assembly. The voice coil has a bigger diameter of 32mm, as opposed to 25mm, although the length is the same at 12mm. The linear excursion capability is 1mm higher than the B110A because of a patented specially shaped extended pole-piece called 'Balanced Drive', which gives a more symmetrical current-vs-displacement characteristic, resulting in lower second-harmonic distortion. The bass performance remains very clean, until it limits abruptly. There is a technical paper on the Wavecor website (**http://bit.ly/pe-feb20-ao4**) which covers the concept in detail, also available for download from the February 2020 page of the *PE* website.

The B110 has a more gradual overload characteristic. At medium levels, the Wavecor has lower distortion. The B110 has a higher usable maximum output, but it costs more than twice the price. Flux modulation reduction measures, consisting of an aluminium pole-piece ring and a copper cap, both missing from the B110A, also reduce

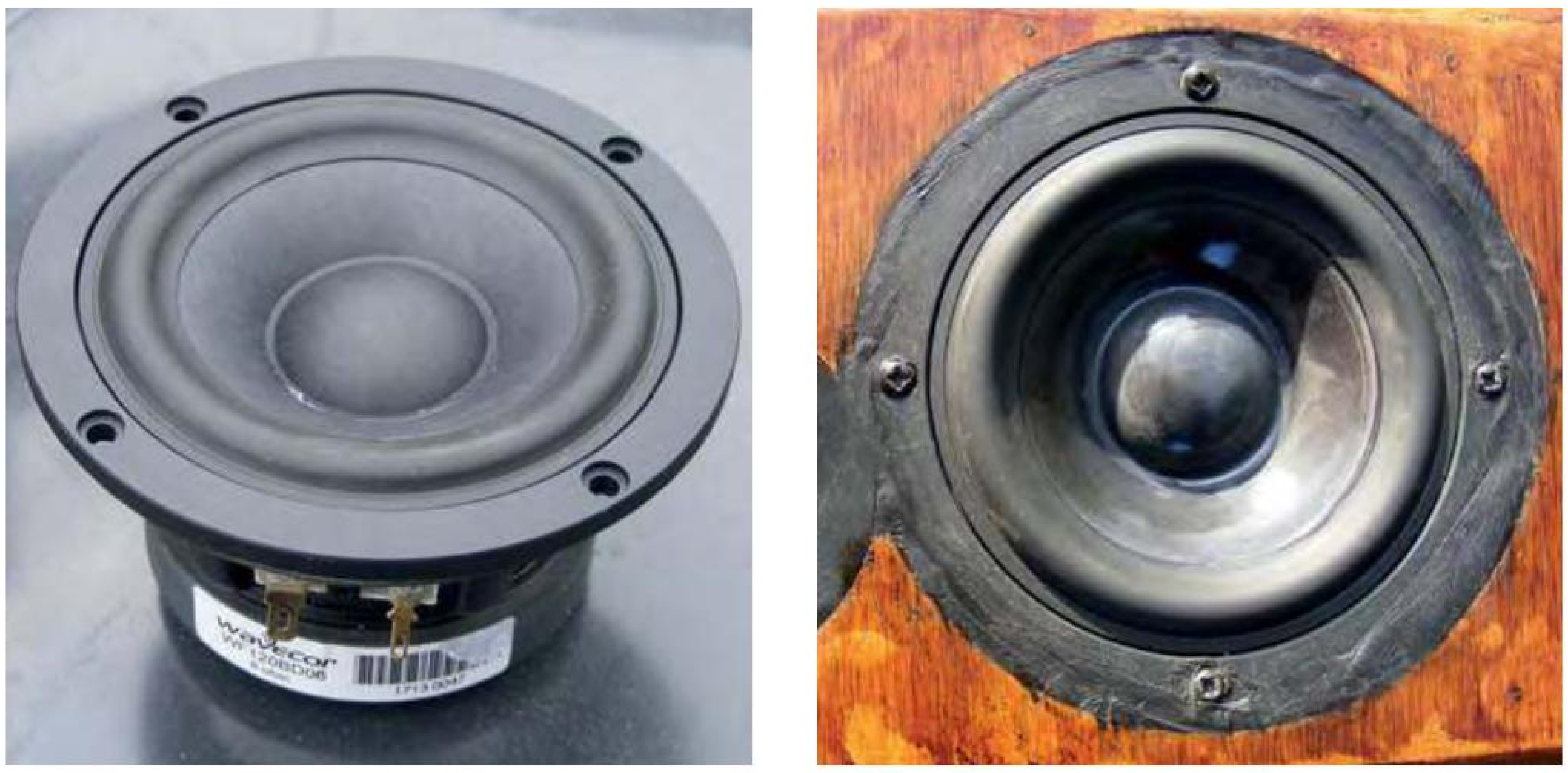


Fig.6. (left) *PE Mini-monitor's* Wavecor WF120BD06 woofer; (right) the Wavecor woofer front mounted in the box (note the doped diaphragm).

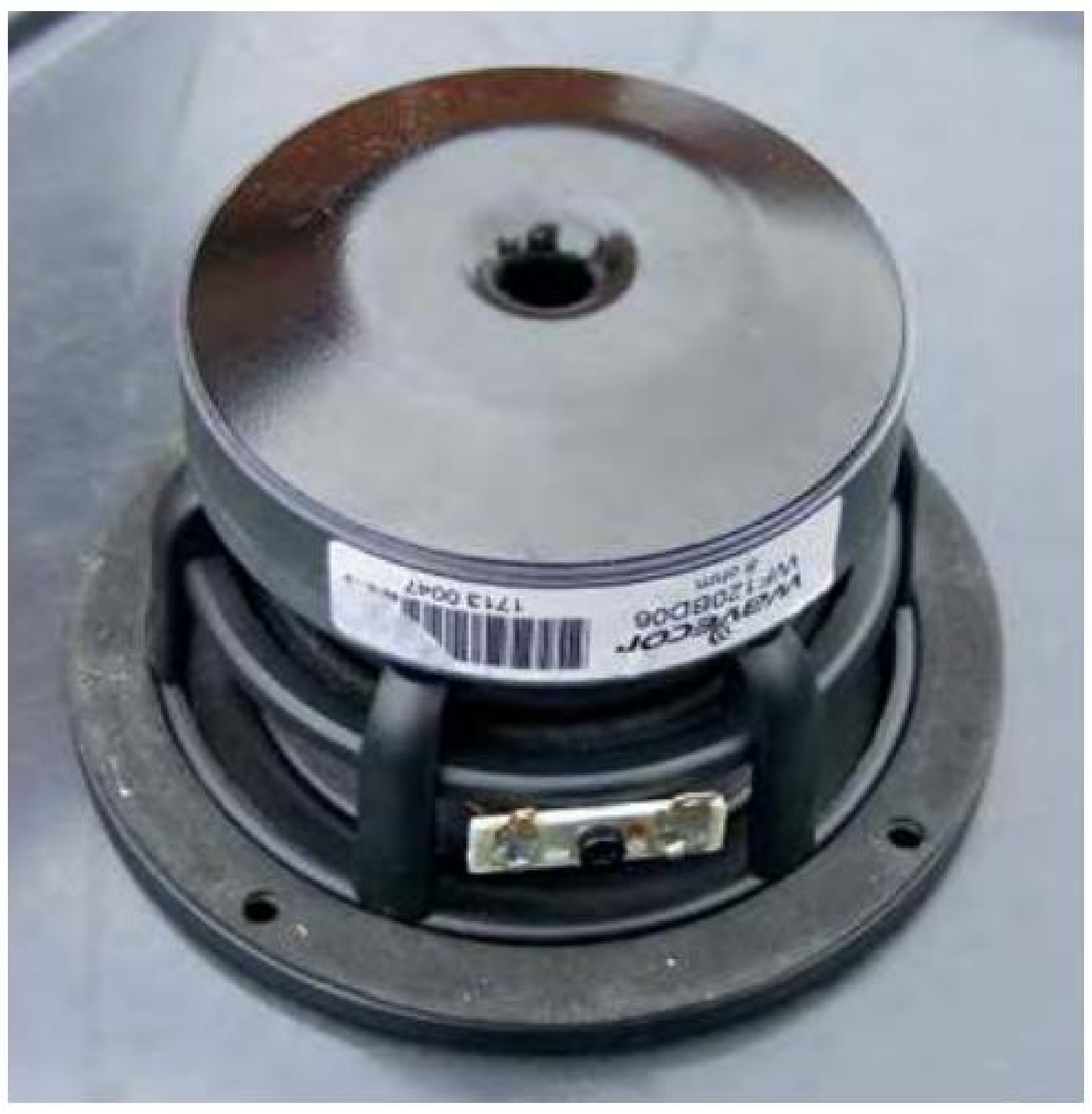


Fig.7. Rear view of Wavecor WF120BD06 woofer; note extensive venting.

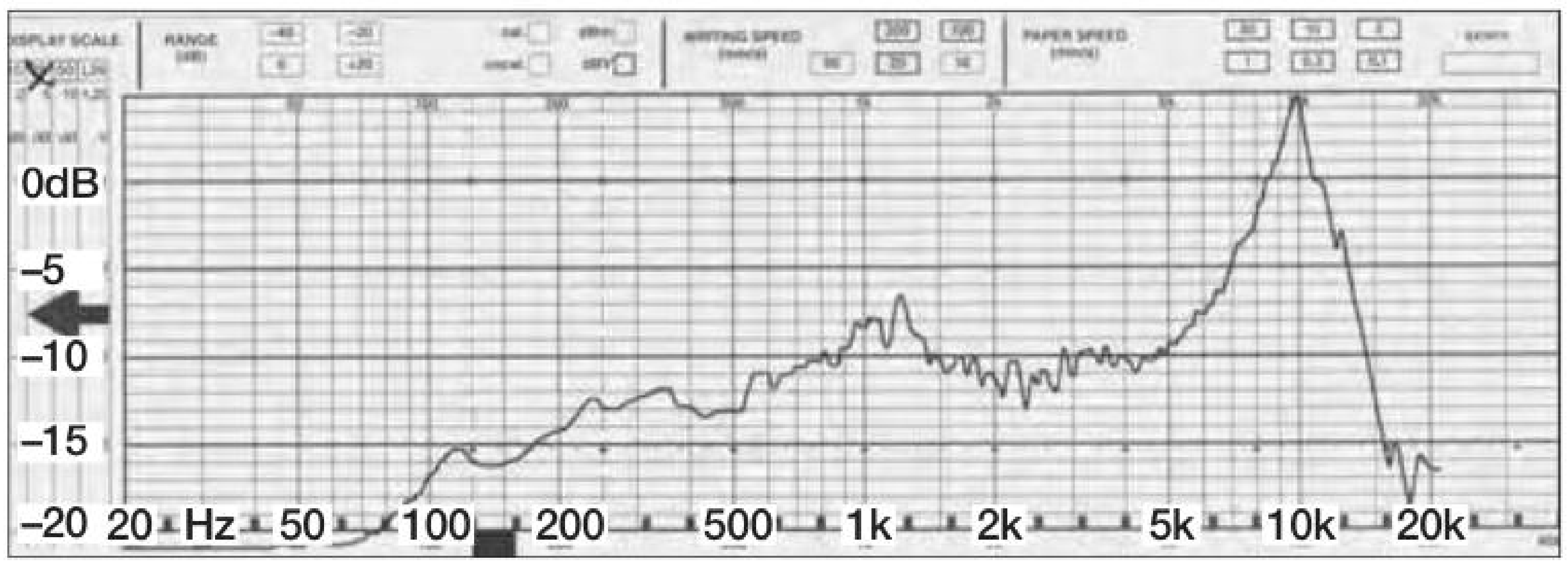


Fig.8. Frequency response of the WF120BD06 woofer in a 5-litre box. The 10kHz peak is characteristic of a stiff cone with low damping. The crossover is designed to stop this resonance being excited.

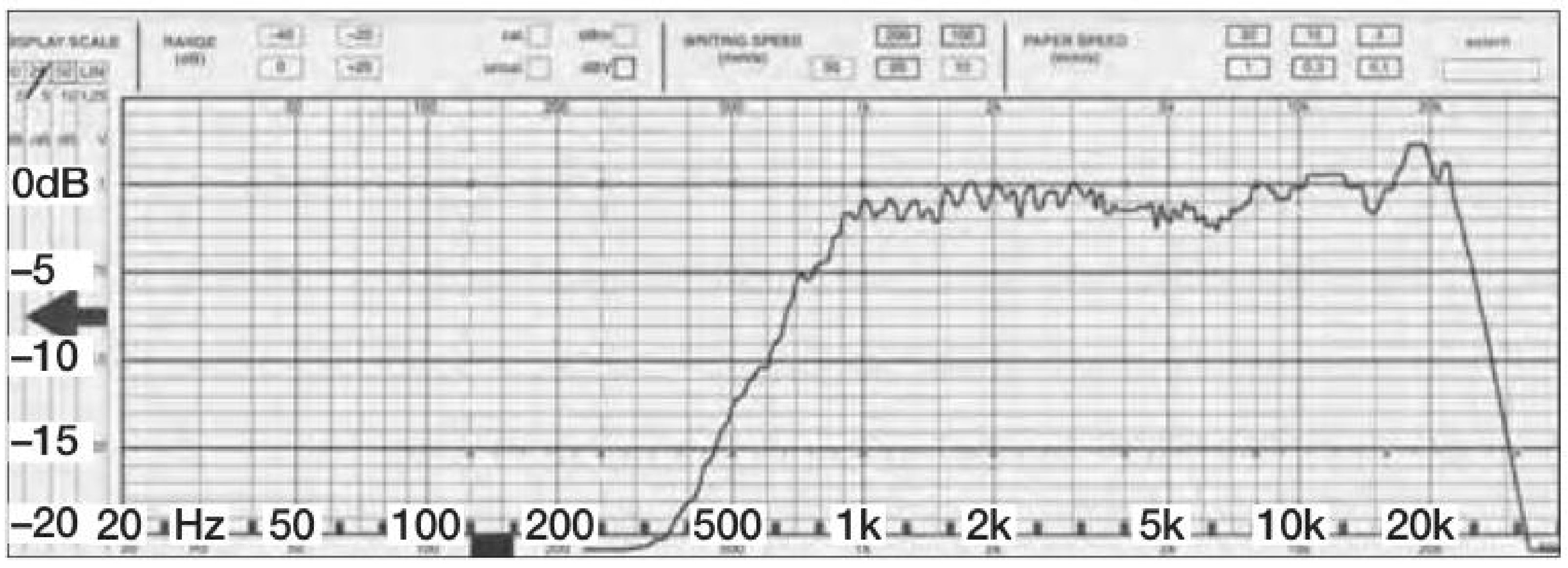


Fig.9. Frequency response of the Wavecor TW022WA04 tweeter flush mounted in box. (No, I can't believe it is that flat!)

distortion. These features are reflected in the impedance curve as a reduced rise at high frequencies. Another plus point is the use of a die-cast chassis as opposed to pressed steel. This avoids ringing, I've often had to support the magnet of the B110 with a damped strut to avoid this effect.

A rather strange feature of the Wavecor bass unit is the vented spider which reduces wind noises and aids voice-coil cooling. It is possible to see the voice-coil through the gaps (see Fig.7). Unfortunately, it is also possible for iron filings to get in. My workshop floor is littered with steel wire off-cuts from soldering resistors, which are a real hazard for speaker magnets. Overall, the suspension of the Wavecor is very low-loss (high Q_m), a useful characteristic for a driver in a sealed box.

Desirable curves

For a successful crossover, the frequency responses of the drivers should overlap by about two octaves when mounted in the cabinet. It can be seen from Fig.8 that the bass unit goes up to around 10kHz and the tweeter goes down to 1kHz shown in Fig.9. The tweeter has the flattest response curve I have ever measured. The woofer is quite odd, with a massive dust-cap resonance at 10kHz and the usual mid-range peak at around 1.2kHz. The high-frequency peak is not as damaging as first appears, since it falls away sharply off axis. Crossover filters do both the job of crossing over and also equalisation of anomalies, so the resulting woofer filter is quite complex.

Doping scandal

The cone and dust cap are made of a hard stiff paper/glass-fibre mix, which ensures pistonic operation up to a higher-than-normal frequency. Unfortunately, when break-up does occur, it does so with great severity, giving rise to the 15dB 10kHz peak. I found this could be reduced to around 10dB by doping the cone with plasticised PVA coating, such as Scola Master Medium (from art suppliers). This also smoothed the response generally and lowered the fundamental resonance, giving better bass as shown in Fig.10. Unfortunately, efficiency is also reduced by a couple of dB. This doping modification is not essential, but it does make the crossover equalisation more effective. I can supply doped drivers if anyone is worried about painting. Note, only the front cone and dust cap should be painted; dope must *not* get on the flexible rubber surround; if it does, wipe off with a damp cloth immediately.

Crossover circuit design

The editor has expressly asked me not to write a thesis on crossover design, so I'll just go through my basic procedure. Most designers use simulation programs such as LTSpice or LEAP to get started. (A precise voice coil electrical model is even available from Wavecor). I'm an experienced, old-fashioned, analogue designer, so I dive straight in with my 'junk-box' of standard value parts and circuit topologies in my head that I've used before. However, this intuitive/iterative/empirical technique only works if you have frequency and impedance-curve plotting equipment, along with a fairly anechoic test room.

First attempt, low-pass section

I like to keep things simple, but not so simple that they don't work. Because of the 10kHz peak, a first-order filter consisting of just a series coil, wouldn't provide sufficient out-of-band attenuation. A basic second-order low-pass filter consisting of a 2.6mH inductor and 15µF capacitor was initially tried, giving the electroacoustic curve shown in Fig.11. This gave a cut-off frequency of 1.2kHz; too low. I raised the frequency by reducing the inductor to 1.2mH, giving the curve in Fig.12. There was now a hump at 1.2kHz, so I went to one of my old tricks of putting in another inductor in series with the woofer to equalise the hump. I added a resistor in parallel, which I could tune to adjust the equalisation 'shelf' required. I reduced the capacitor to 6.8µF to up the roll-off, giving a flat response to 2.5kHz, as shown in Fig.13 near the required crossover frequency. The resulting electrical response

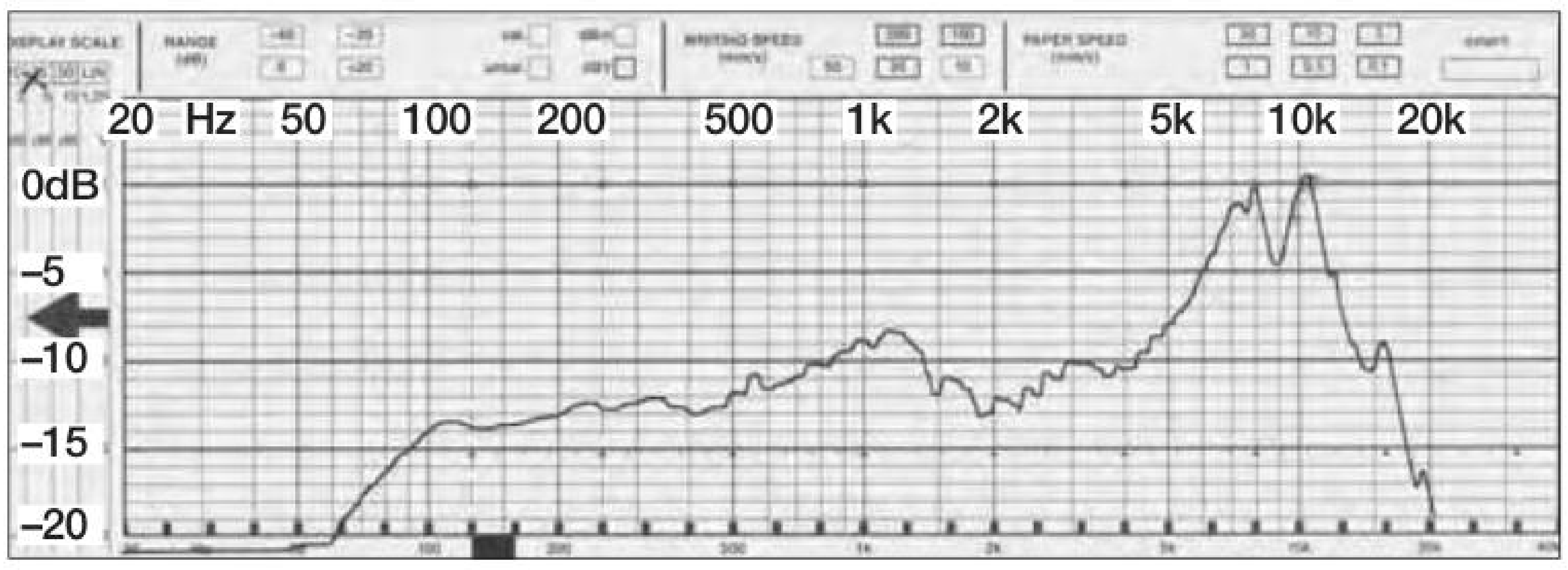


Fig.10. Wavecor WF120BD06 woofer frequency response after doping. Dust cap resonance has dropped by 6dB.

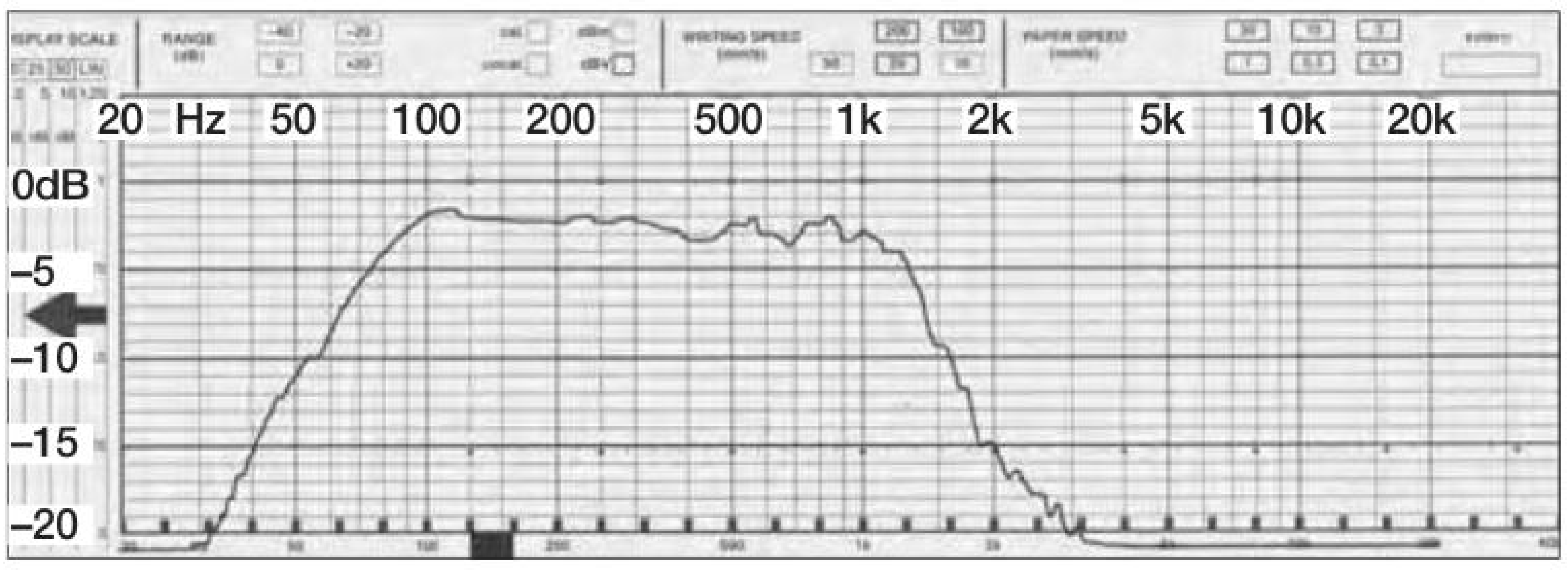


Fig.11. First attempt at second-order low-pass filter using a 2.6mH coil and 15µF capacitor. Selected frequency too low at 1.2kHz.

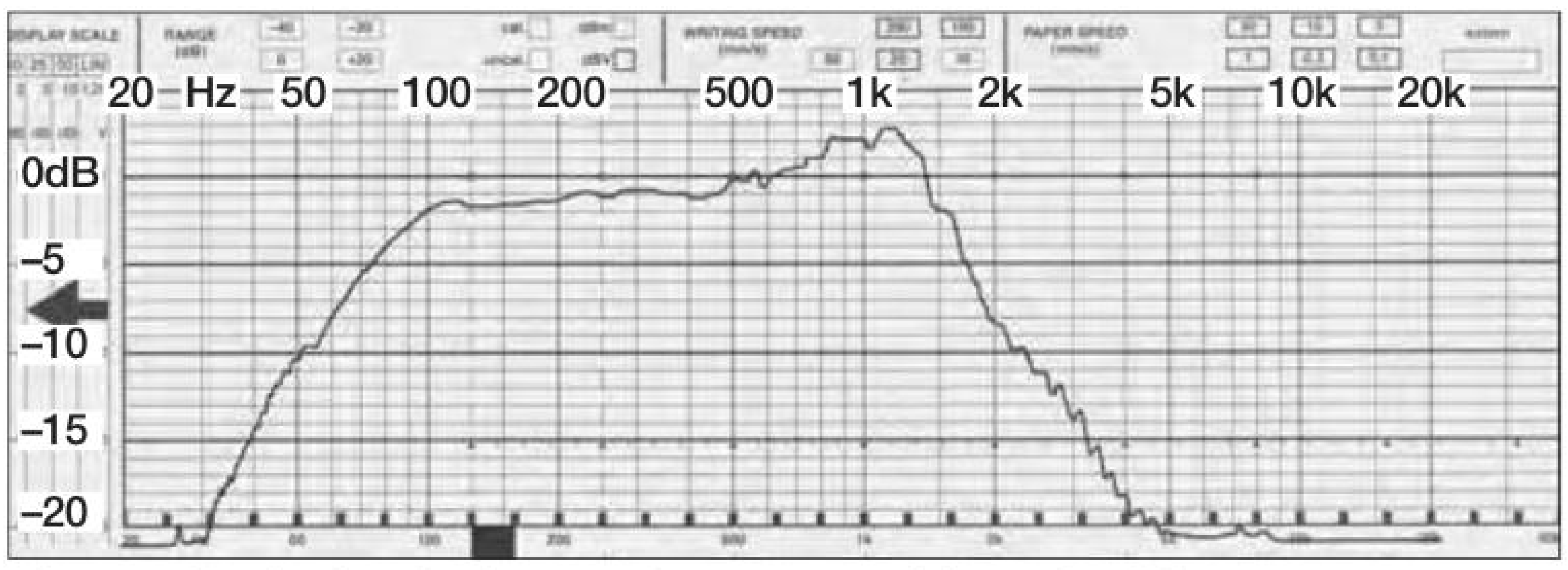


Fig.12. Reducing inductor size to 1.2mH pushed frequency up, but a 'hump' at 1.2kHz appears.

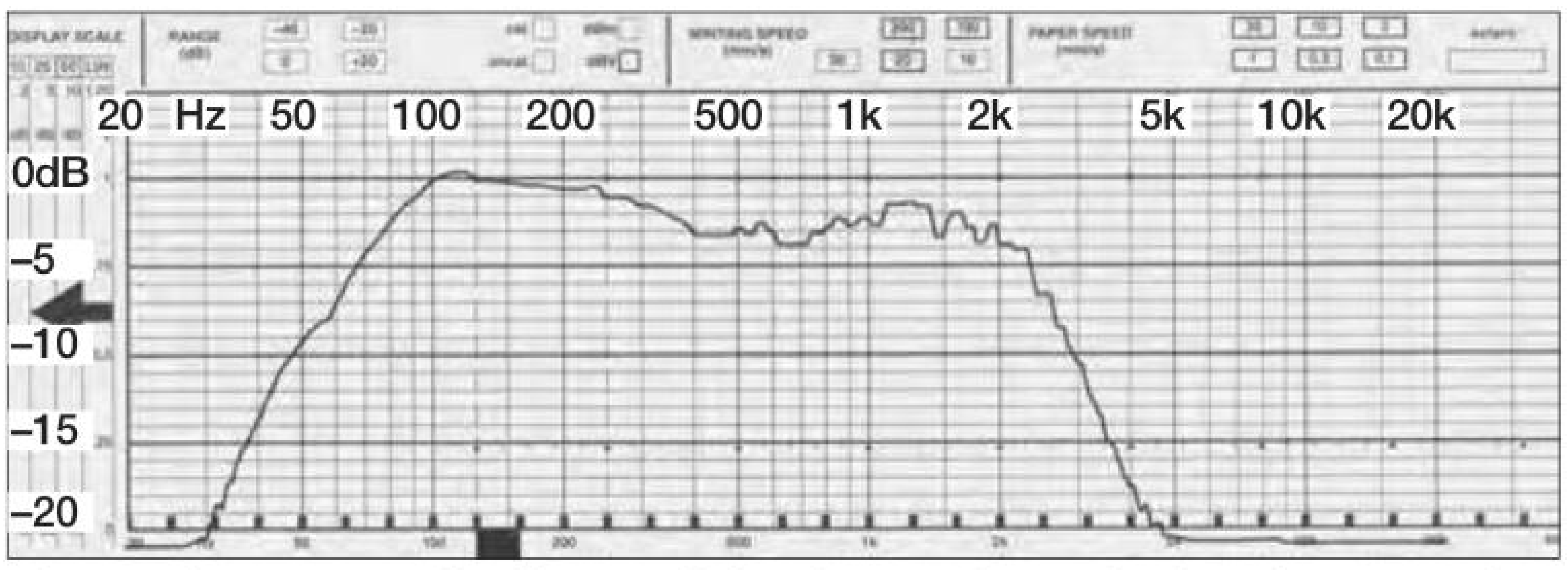
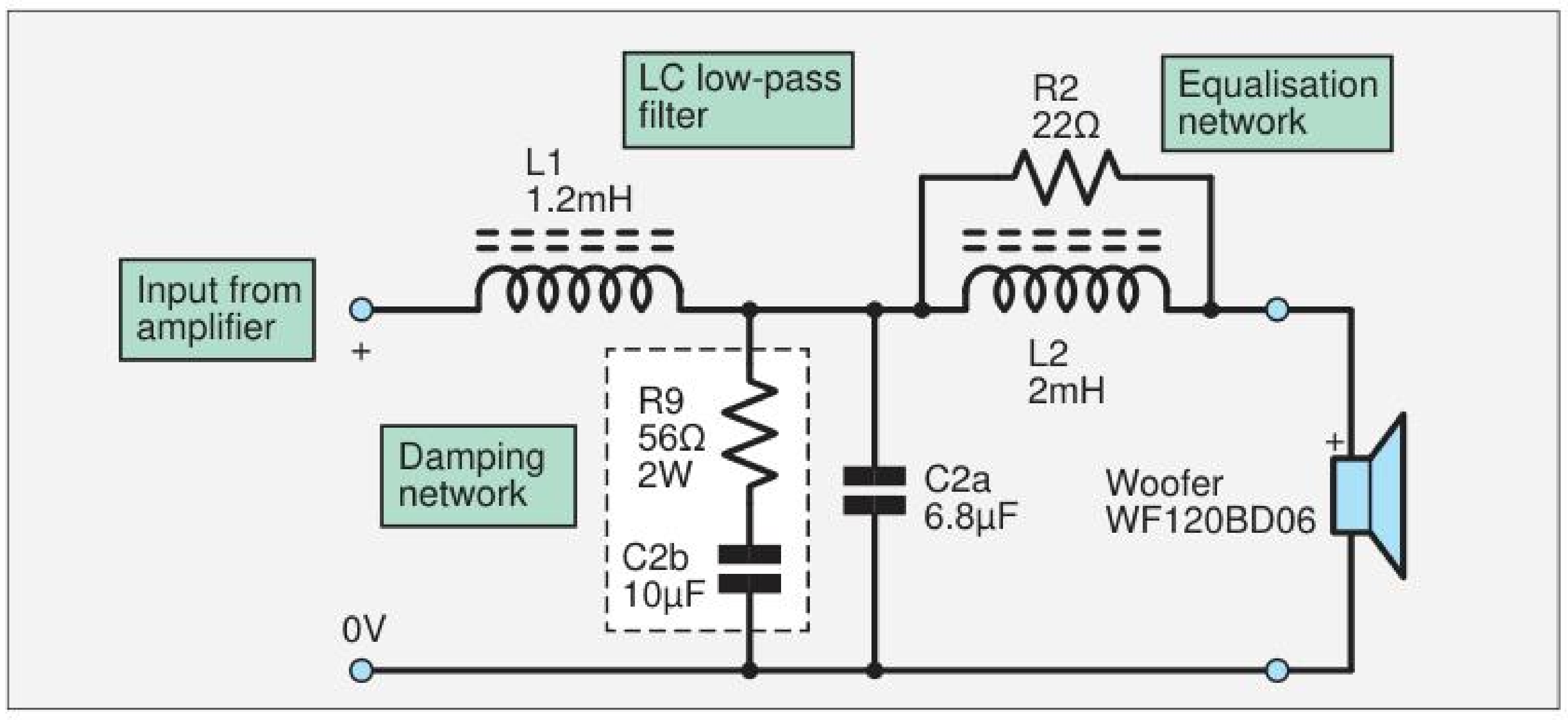


Fig.13. An extra coil with parallel resistor, plus reducing the capacitor to 6.8µF bends the electro-acoustic curve to the required shape.


LC low-pass filter
R2
22Ω
Equalisation network
L1
1.2mH
Input from amplifier
+
L2
2mH
Damping network
R9
56Ω
2W
C2a
6.8µF
Woofer
WF120BD06
+
C2b
10µF
0V

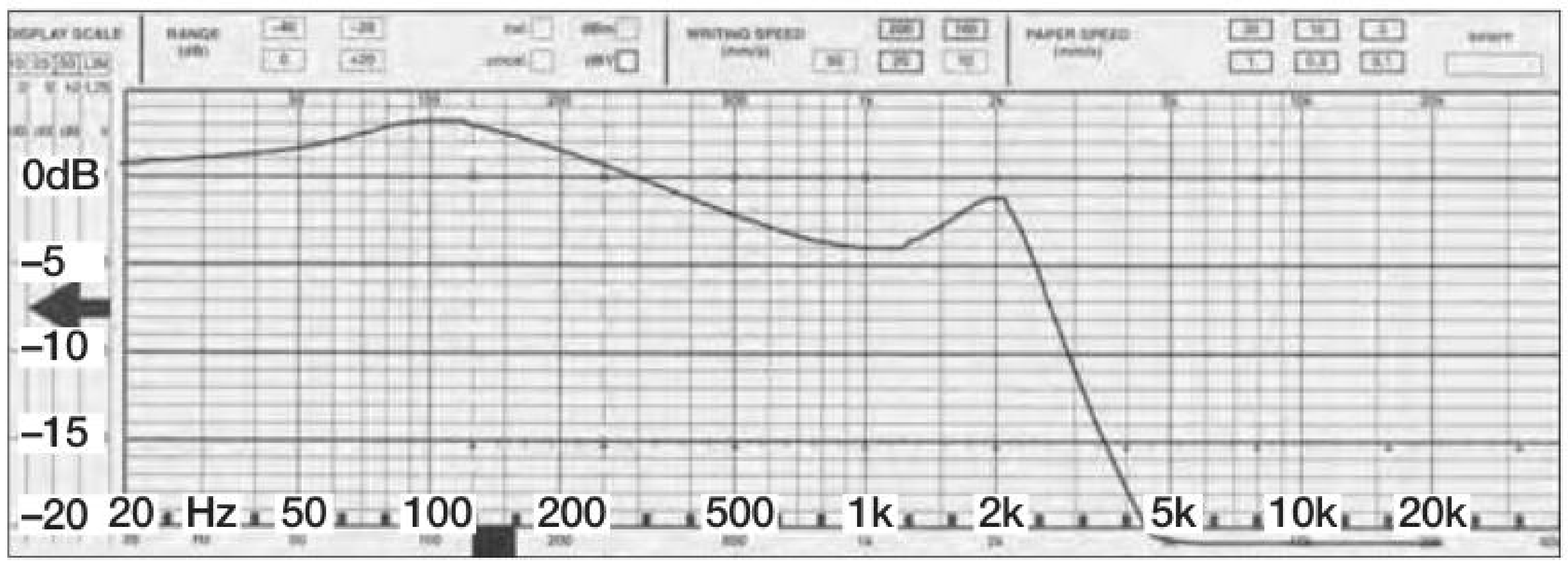


Fig.14. (left) Wavecor crossover low-pass circuit and (right) its electrical response.

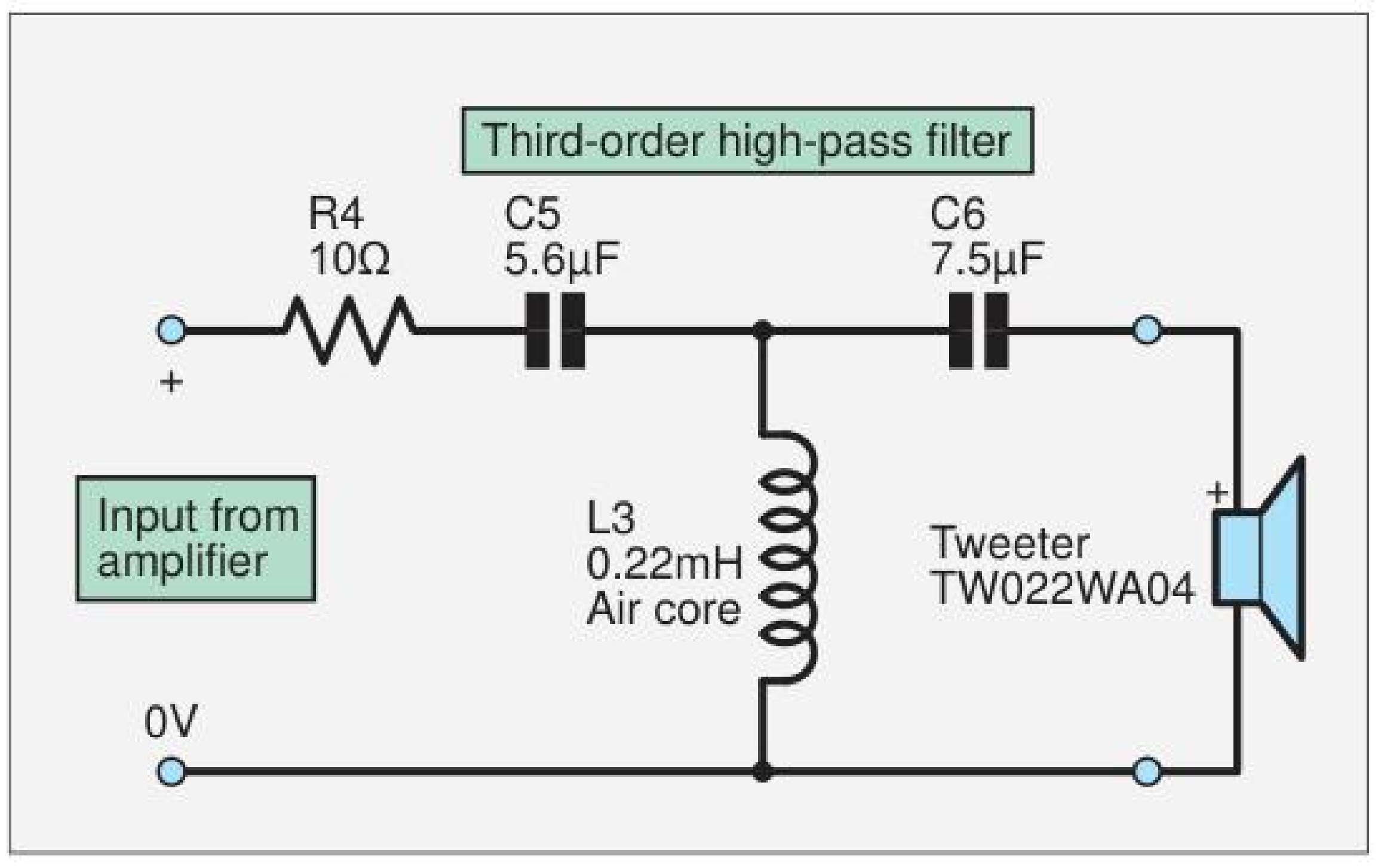

Third-order high-pass filter
R4
10Ω
C5
5.6µF
C6
7.5µF
+
Input from amplifier
L3
0.22mH
Air core
Tweeter
TW022WA04
+
0V

Fig.15. Initial high-pass circuit, standard third-order filter, but feeding a 4Ω tweeter.

and circuit are illustrated in Fig.14. This approach is 'backwards' – most designers design the electrical curve first. I don't, because it is the acoustic output that matters. It sounds like quick work, but to get to this point took around five hours.

High-pass section

Now we have a working low-pass section, which is always the most difficult bit, so next we have to design the high-pass. Since the crossover frequency is quite low for a 22mm tweeter, a minimum of third-order will have to be used, because too much low frequency input could cause distortion and possibly damage the tweeter. The tweeter has a 4Ω coil, so inductor L3 in the centre of the T-section is smaller than for a conventional 8Ω design, and the capacitor is bigger. Because the crossover is a bit lower than the standard 3kHz used in most speakers, all the values are increased again. See Fig.15 for the high-pass circuit. The input resistor R4 sets the tweeter attenuation and its relative level to the woofer. This is a very sensitive adjustment and is dependant on room acoustics and positioning. The value can range from 12 to 5.6Ω. I found the optimum in my living room was 10Ω and in the workshop 6.8Ω. In the end, I compromised with 7.5Ω (I used a 27Ω wired across 10Ω, giving 7.3Ω). If the woofer is undoped, the resistor will have to be reduced by around 1 to 2Ω. Incidentally, 10cc's song, *I'm Not in Love*, is a good test for tweeter level. If the strummed tizzy miced-up electric guitar can be heard clearly on the left and the vocal isn't too sibilant and spitty, the resistor value is correct. Since a relatively high-value resistor is in series with the tweeter input, it means thin cheap wire can be used to feed the tweeter circuit if bi-wiring is used.

Basic circuit

The circuit in Fig.16 is not the final crossover design, but the basic curves shown in 16b to 16e are now satisfactory. Next month, we are going to do the vital impedance check to make sure it doesn't go below 6.7Ω necessary for it to qualify as a 8Ω speaker. I'm also going to do some minor crossover additions to improve the subjective frequency response, called 'voicing'.

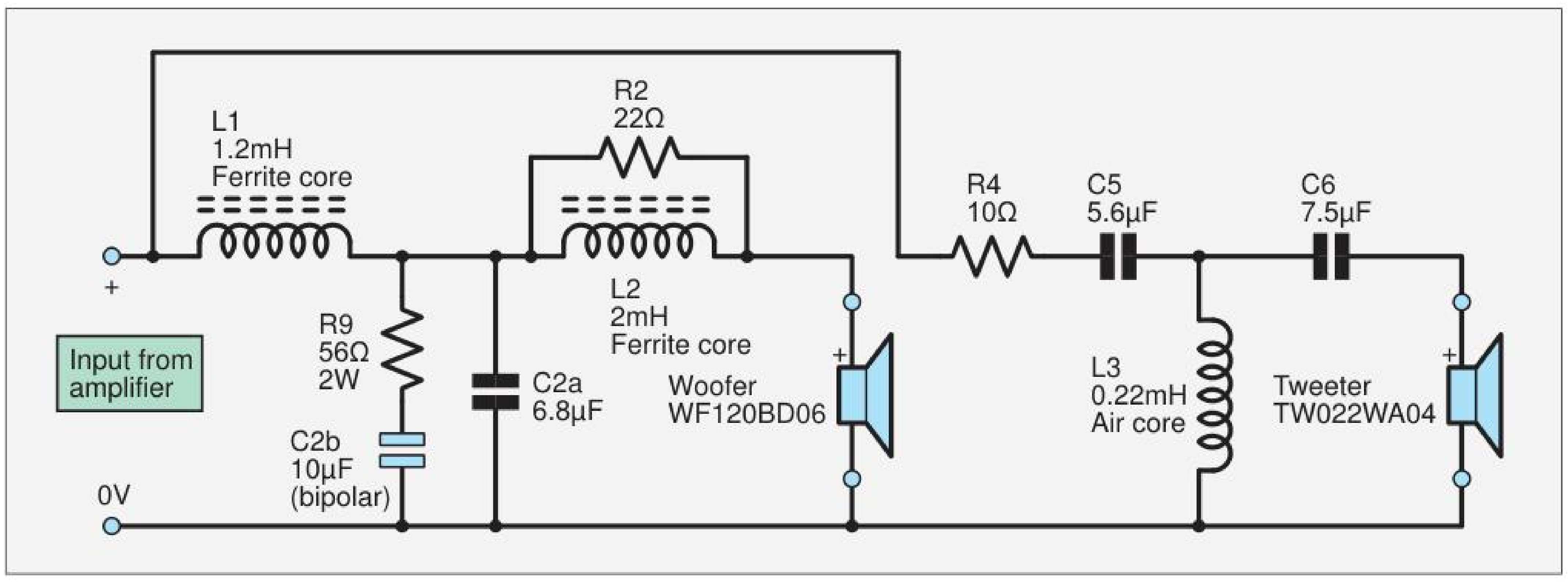
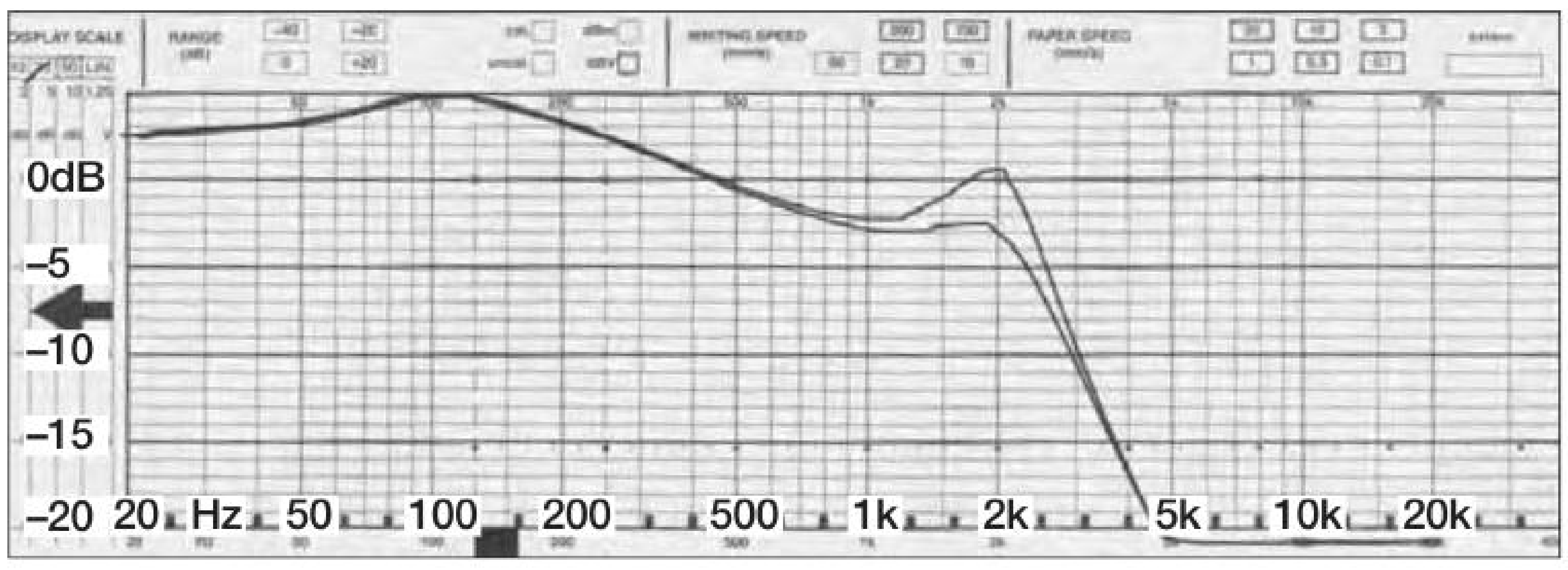

L1
1.2mH
Ferrite core
R2
22Ω
R4
10Ω
C5
5.6µF
C6
7.5µF
+
L2
2mH
Ferrite core
R9
56Ω
2W
Input from amplifier
C2a
6.8µF
Woofer
WF120BD06
+
L3
0.22mH
Air core
Tweeter
TW022WA04
+
C2b
10µF
(bipolar)
0V

Fig.16a. Complete provisional crossover circuit obtained by combining the low-pass section in Fig.14 with the high-pass in Fig.15.



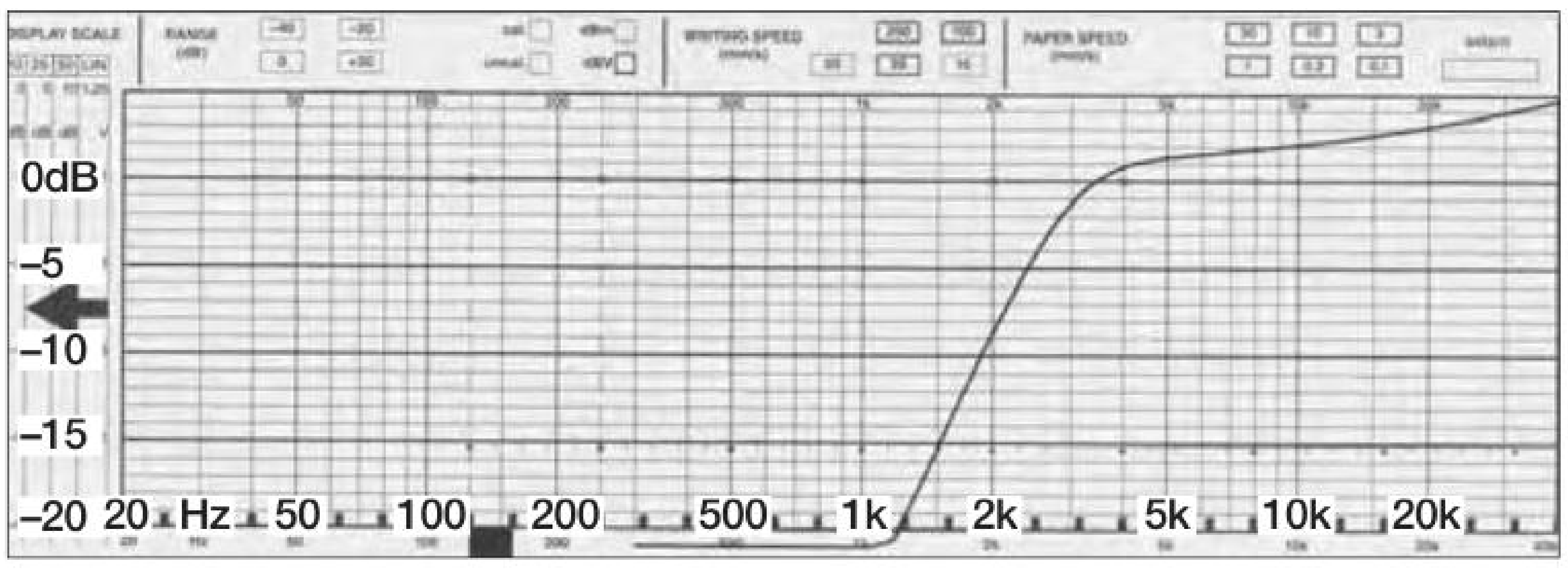
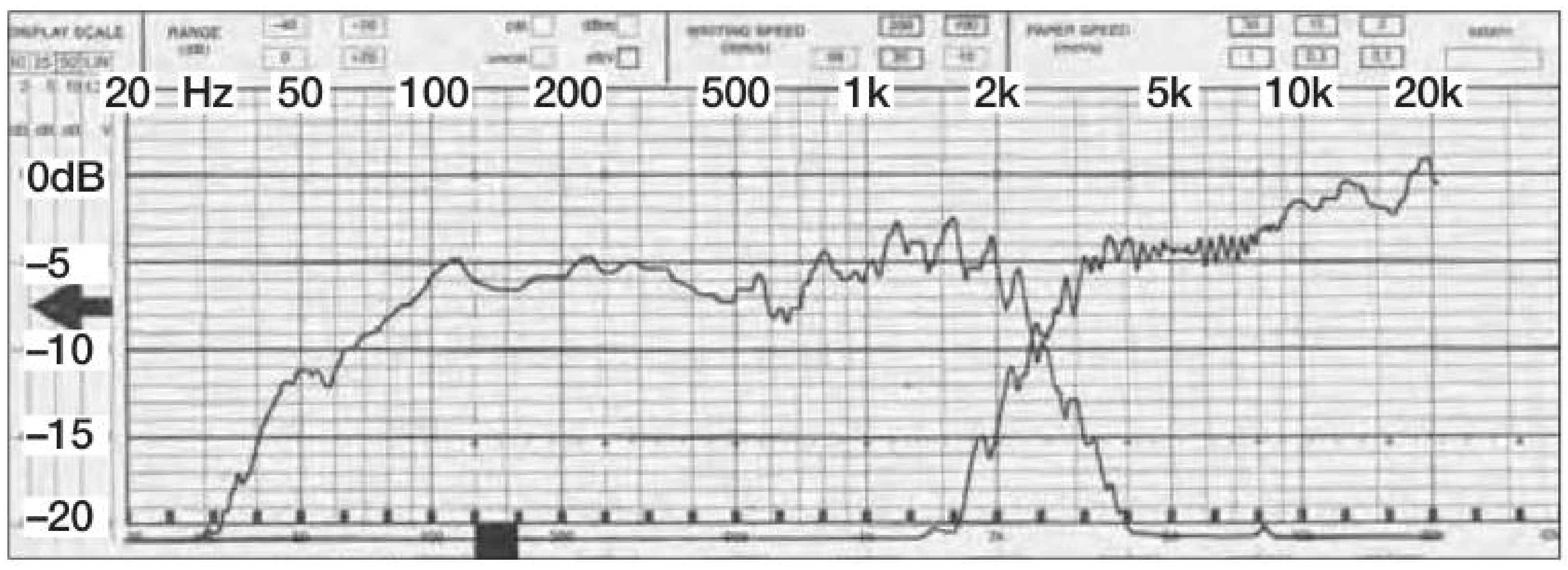
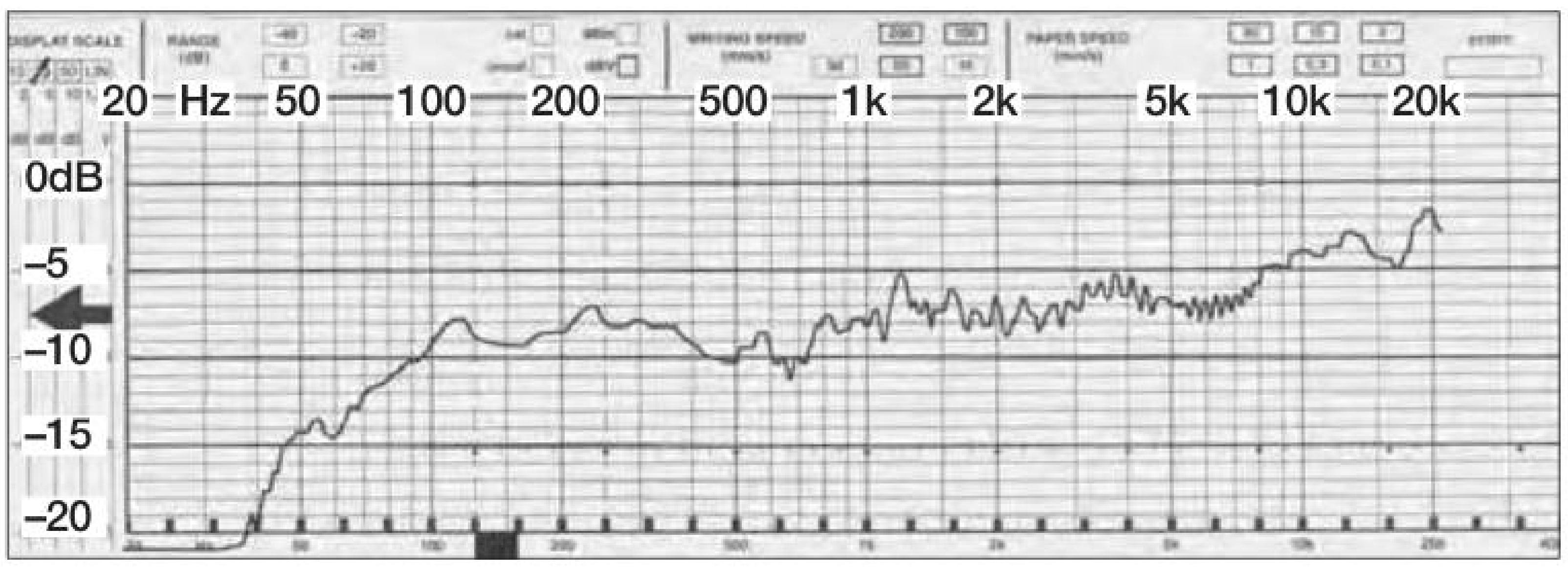


Fig.16b (top left) Low-pass electrical response curve displaying the effect of adding the damping network shown dotted in Fig.14 Fig.16c (bottom left) resulting electro-acoustic curves of woofer and tweeter overlaid to show crossover at 2.5kHz; Fig.16d (top right) electrical response of the high-pass filter; Fig.16e (bottom right) The overall system response with damping resistor.





Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 13: Controlling RGB LEDs and building a Mood Light

Fig.1. The Micromite *Mood Light* has many features and is controlled via an IR remote. It is shown here inside a modified Ikea FADO table lampshade.

Over the last couple of months we have explored serial data communication techniques. This included writing code to interpret key presses from a capacitive keypad, and also how to use bit-banging to display characters on an LED matrix. This month, we will show you how to use MMBASIC's SPI commands to perform the function of bit-banging, and we'll use this method to control RGB LEDs. Once we have learnt how easy it is to set the colour and brightness of an LED, we will put this knowledge into practice and build a new mini-project – a fully featured, IR-controlled *Mood Light* (see Fig.1).

Colourful LEDs

RGB LEDs differ from normal LEDs – they can to create virtually any colour by mixing the appropriate amount of red, green, and blue light. They are able to do this because an RGB LED (as its name implies) contains a red LED, a green LED and a blue LED. These three LEDs are positioned very closely to each other inside a single package. By adjusting the voltage, and hence the current supplied to each of the three LEDs, the human eye is tricked into seeing a solid colour. This is exactly the technique used in colour TV for illuminating each individual RGB pixel on the screen.

There are many different RGB LEDs available today, but they typically fall into one of two main types:

1. Standard 4-pin RGB LED – these have a red, green, and blue pin connected to the 'outside world', along with a common pin (see Fig.2a). By applying various voltages directly to the RGB pins, the LED emits a range of colours.
2. Smart RGB LED – these integrate a controller chip inside their package, which in turn is connected to (and drives) the red, green, and blue LEDs. Smart RGB LEDs typically have a serial-communication link to the outside world to receive appropriate data to control the overall colour and brightness of the LED. Smart RGB LEDs are usually, but not always, packaged as a surface-mount device (SMD, see Fig.2b). Types of smart RGB LEDs that you have possibly heard of include the WS28xx, NeoPixel, DotStar and APA102.

A nice analogy is that the 'standard' type can be considered as an analogue LED (requiring voltages), and the 'smart' type viewed as a digital LED (requiring data). We will be using the smart digital type in our discussions this month, and use several to build the *Mood Light*. A useful point to understand is that a smart RGB LED (which is based on a serial communication link) includes four pins: Clk In, Data In, Clk Out and Data Out. This allows multiple smart LEDs to be 'daisy-chained' (the output of one feeding into the input of the next) to create a string of LEDs, while retaining the ability to individually control each LED in the string (see Fig.3).

The Blinkt! module

From the many RGB LEDs and modules available to choose from, we've selected

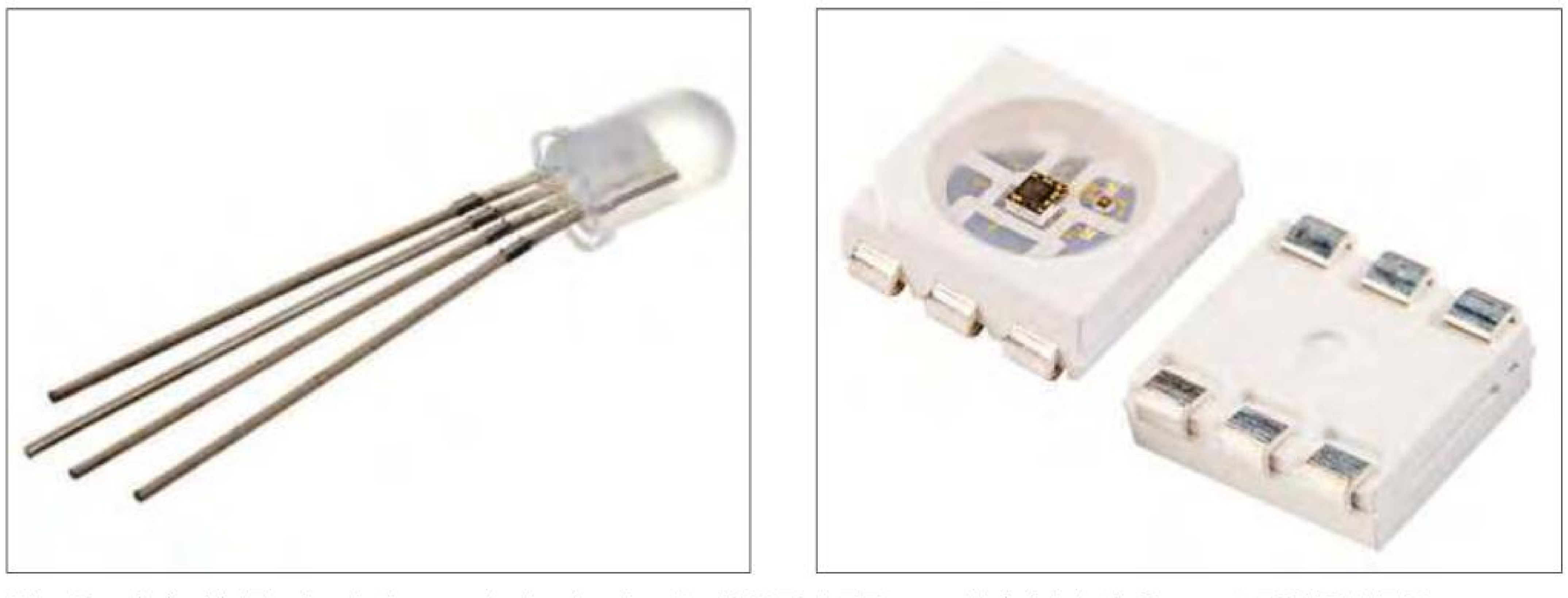


Fig.2. a) (left) Typical through-hole 4-pin RGB LED and b) (right) Smart RGB LED – here, two views of a single APA102 SMD package.

Micromite code

The code in this article is available for download from the *PE* website.

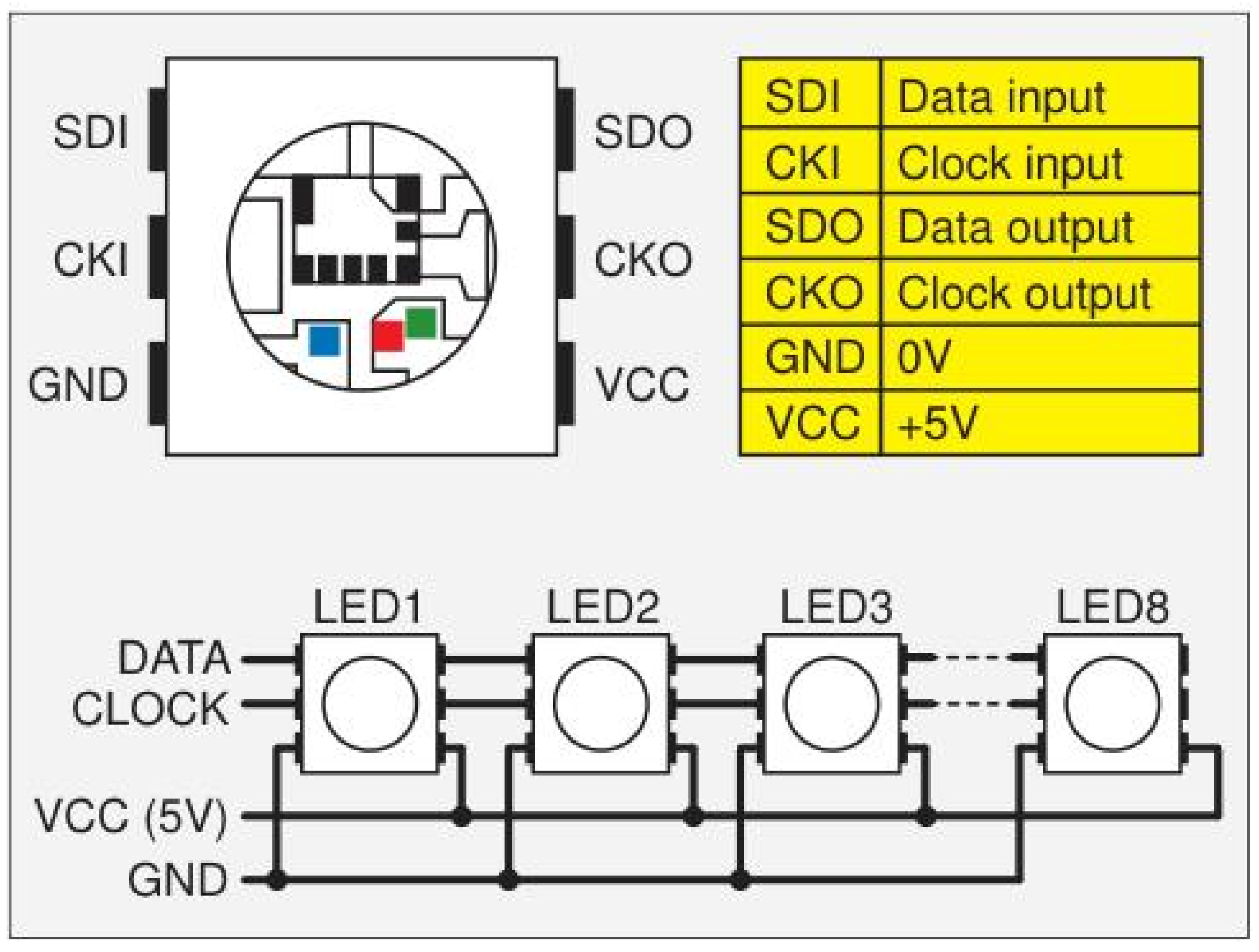

SDI
CKI
GND
SDO
CKO
VCC
SDI Data input
CKI Clock input
SDO Data output
CKO Clock output
GND 0V
VCC +5V
LED1
LED2
LED3
LED8
DATA
CLOCK
VCC (5V)
GND

Fig.3. Smart RGB LEDs can be cascaded to create a string (pinout shown here is for the APA102).

the Blinkt!, manufactured by Pimoroni. It is one of the lowest-cost smart RGB LED modules available, and it comprises of not one, but eight ultra bright, and individually controllable APA102 LEDs (connected together as shown in Fig.3). The Blinkt! is actually designed to be plugged directly into a Raspberry Pi's 40-way GPIO connector. However, as with any Raspberry Pi add-on (or any Arduino shield), there is nothing preventing us from connecting it to a Micromite. Even though the Blinkt! has a 40-way female socket, only four pins are used; two for 5V power (5V/0V), and two for the synchronous serial link (Clock and Data) – see Fig.4. So we need just four wires to connect the Blinkt! to the Micromite's *Development Module*, as shown in the schematic in Fig.5. Also shown are the connections to the IR receiver that we will use later for the *Mood Light*. However, before we begin writing any code, we first need to understand what data the APA requires to function.

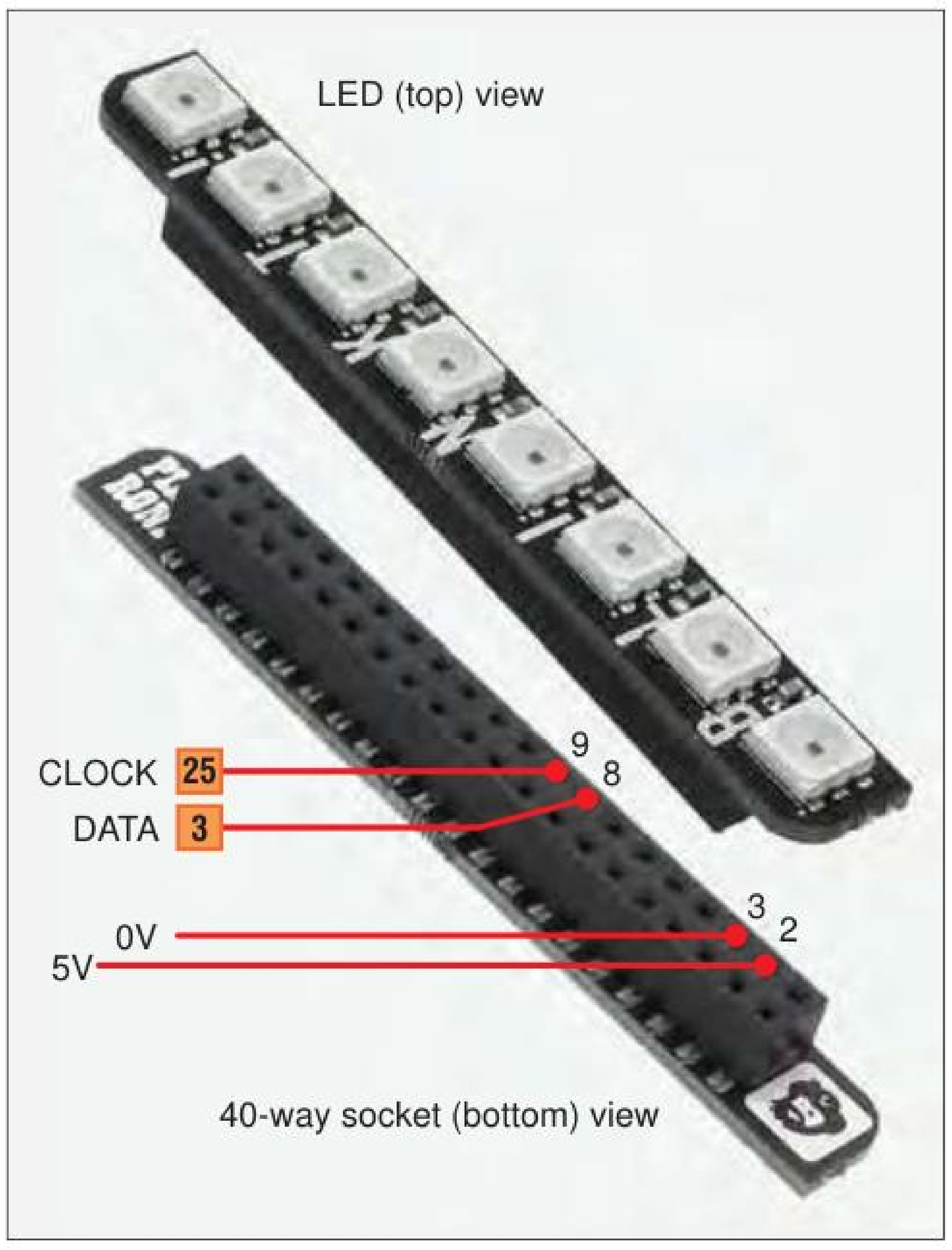

LED (top) view
CLOCK 25
DATA 3
0V
5V
9
8
3
2
40-way socket (bottom) view

Fig.4. The Blinkt! is a low-cost Raspberry Pi module containing eight ultra-bright APA102 RGB LEDs. Each RGB LED can individually be set to any colour and brightness via the single two-wire serial interface.

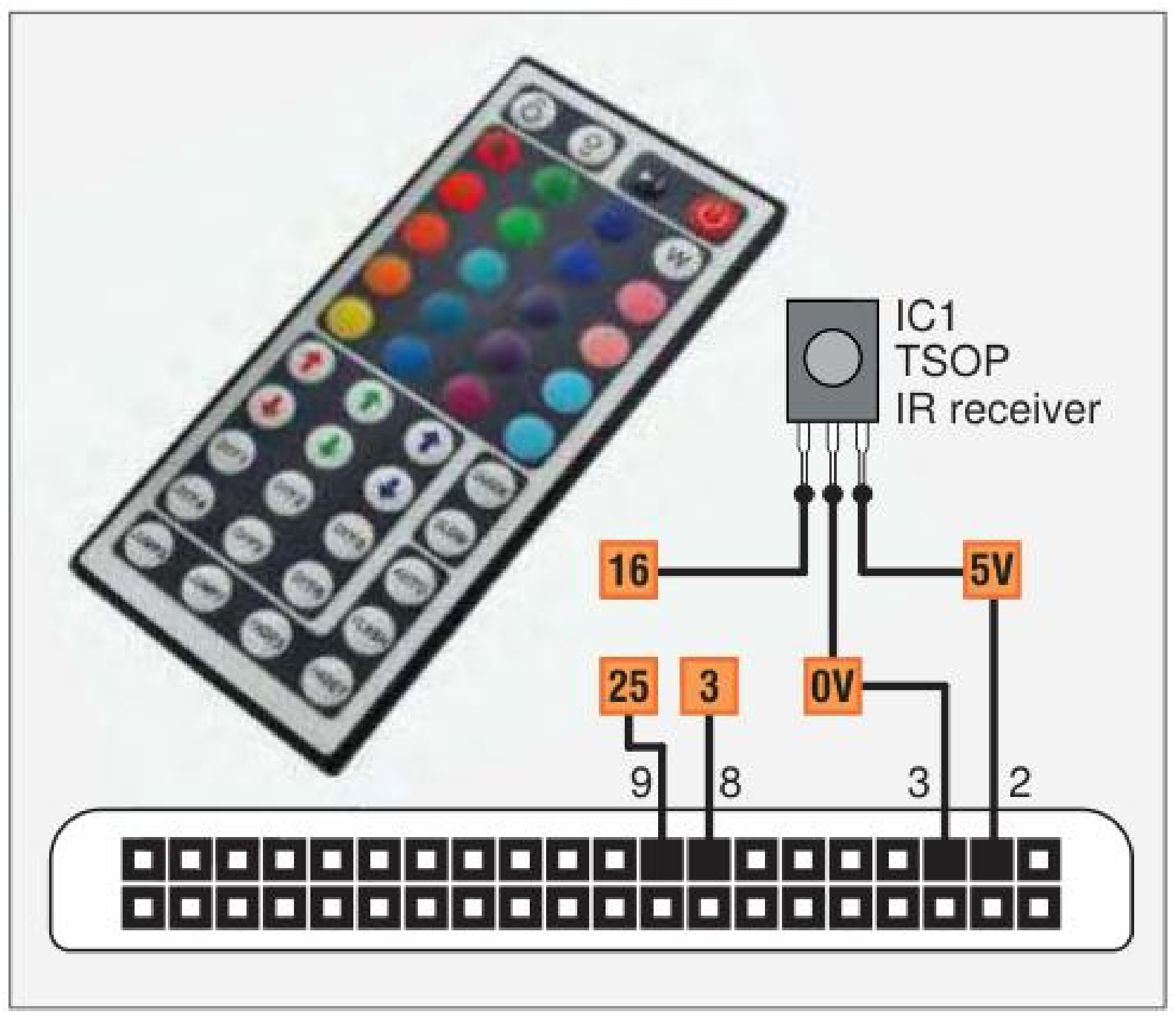

IC1
TSOP
IR receiver
16
5V
25
3
0V
9
8
3
2

Fig.5. The Micromite *Mood Light* requires just three components: an IR remote control and receiver, and the Blinkt! module – (plus some Micromite code!). The connections to the Blinkt! and the IR receiver are shown here.

The APA102 data format

From the APA102 datasheet (**http://bit.ly/pe-feb20-APA**) we can summarise the following requirements to set the overall brightness of the smart RGB LED, as well as the red, green and blue colour intensities:

1. Send 32 zeroes (`0`) for the 'start-of-message' frame
2. Send 4-byte LED frame (data for brightness, and the RGB intensities):
   - byte 1: `111xxxxx` where `xxxxx` = brightness value between `0` (off) and `31` (max)
   - byte 2: `B` value between `0` (blue intensity off) and `255` (max blue intensity)
   - byte 3: `G` value (`0` to `255`)
   - byte 4: `R` value (`0` to `255`)
3. Repeat step 2 for each LED in the strip (eight times for the Blinkt!)
4. 32 zeroes (`0`) to begin the 'end-of-message' frame
5. Send an additional eight zeroes (`0`) to complete the 'end-of-message' frame (for 8 LEDs).

The above is represented diagrammatically in Fig.6. If you look closely, you will see that we need to send multiple 8-bit chunks of data (multiple bytes). Let's look at this in more details.

Seeing red!

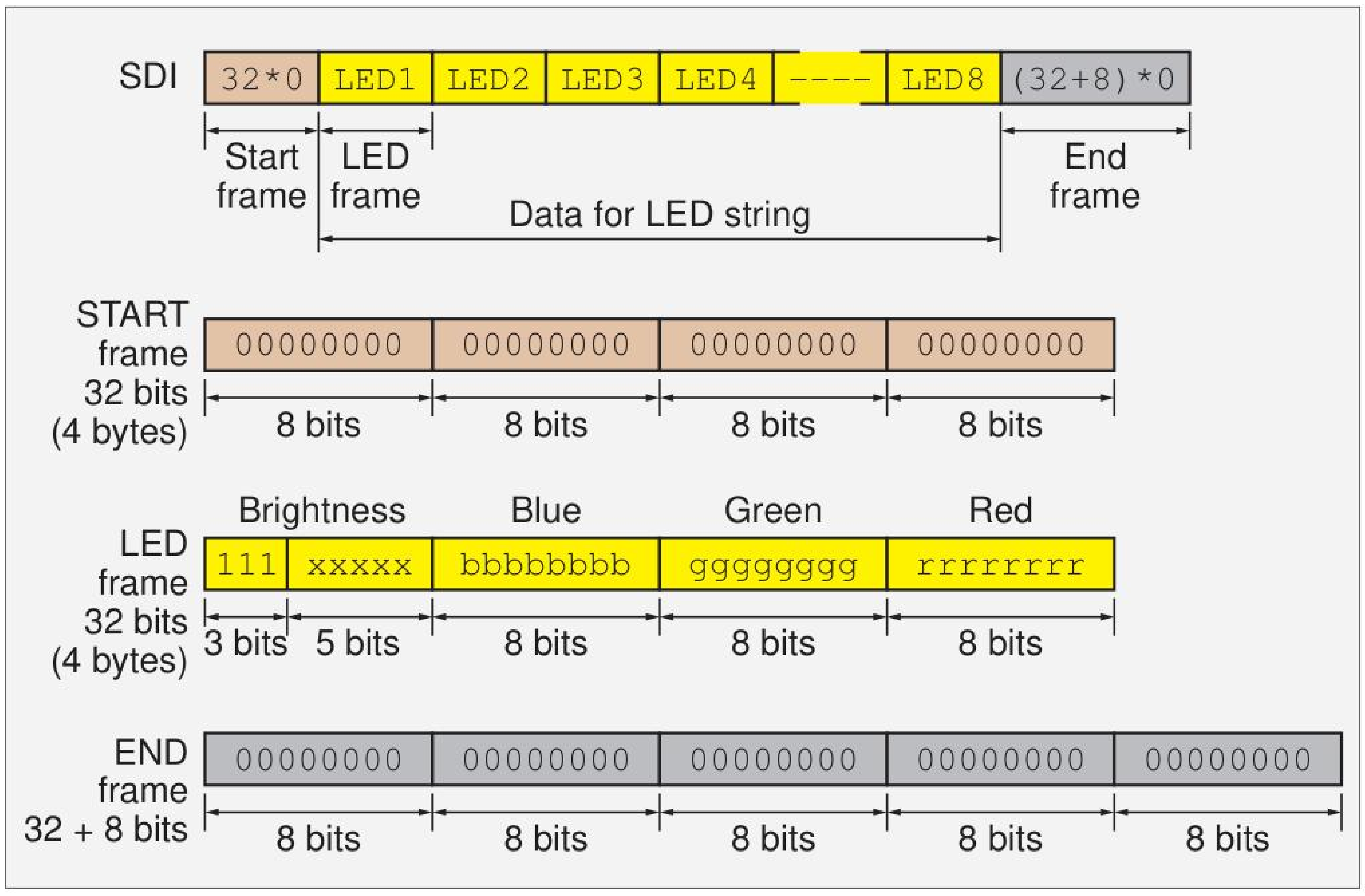
We'll now discuss how to set all eight LEDs on the Blinkt! to full red intensity, and at maximum LED brightness. Referring to Fig.6, you will see that the bytes we need to send are:

(START frame [4 bytes]) `0,0,0,0`
(LED 1 frame [4 bytes]) `255` (the 8-bits: `111 11111`), `0` (no blue), `0` (no green), `255` (full red intensity)
(LED 2 frame [4 bytes]) `255,0,0,255`
(LED 3 frame [4 bytes]) `255,0,0,255`
(LED 4 frame [4 bytes]) `255,0,0,255`
(LED 5 frame [4 bytes]) `255,0,0,255`
(LED 6 frame [4 bytes]) `255,0,0,255`
(LED 7 frame [4 bytes]) `255,0,0,255`
(LED 8 frame [4 bytes]) `255,0,0,255`
(END frame [4+1 bytes]) `0,0,0,0,0`

So if we send the above 41 bytes to the Blinkt!, then we will see all LEDs set to red at full intensity ('redness'), and at maximum brightness. We will demonstrate this shortly, but first we'll discuss how to send this data to the Blinkt!

Bit-banging with the SPI command

Last month we sent data to the 8×8 LED matrix module by bit-banging it with raw code. In summary, the Data signal was set as required to either a high (`1`), or a low (`0`) logic level, and then the Clock signal was pulsed to load the data bit into the LED matrix driver chip. This was repeated for each bit sent. In last months code we used `SUB MAXwrite(value)` to bit-bang a 16-bit value. We could modify `SUB MAXwrite(value)` to clock out 8 bits (instead of 16 bits), and then call it


SDI
32*0
LED1
LED2
LED3
LED4

LED8
(32+8)*0
Start frame
LED frame
Data for LED string
End frame
START frame 32 bits (4 bytes)
00000000
00000000
00000000
00000000
8 bits
8 bits
8 bits
8 bits
Brightness
Blue
Green
Red
LED frame 32 bits (4 bytes)
111
xxxxx
bbbbbbbb
gggggggg
rrrrrrrr
3 bits
5 bits
8 bits
8 bits
8 bits
END frame 32 + 8 bits
00000000
00000000
00000000
00000000
00000000
8 bits
8 bits
8 bits
8 bits
8 bits

Fig.6. The serial-data format required to control a string of APA102 RGB LEDs.

41 times, passing each byte shown above, one at a time, in the correct sequence. However, all this can be greatly simplified by replacing the `SUB` code with a single SPI command, which in effect automates the bit-banging for us.

The Micromite has three pins dedicated to SPI:

- Pin 25 SPI Clock
- Pin 3 SPI Data Out
- Pin 14 SPI Data In (not used here)

To use the SPI pins, they first need to be configured at the start of our code with the single command: `SPI OPEN` *`speed`*`,` *`mode`*`,` *`bits`*. Please refer to the *User Manual* (**geoffg.net/Micromite.html** – see Appendix D) for detailed information regarding the SPI parameters. In the limited space here we will define the exact line of code we need to use to configure the SPI pins: `SPI OPEN 1000000,0,8` (the `8` refers to 8 bits at a time; ie, one byte at a time).

Once the SPI pins have been configured, we can send bytes of data with the following single command: `SPI WRITE` *`nbr`*`,` *`data1`*`,` *`data2`*`,...` where *`nbr`* represents the number of data-bytes we are sending, and *`dataX`* are the individual bytes.

Using the above information we can begin to write some simple test code. First, make the four connections between the Blinkt! and the Micromite, as shown in Fig.5 (there is no need to connect the IR receiver just yet). Next, enter the following six lines of code (remember to save any existing program code in the Micromite, should you need to!).

```
SPI OPEN 1000000,0,8
SPI WRITE 4, 0,0,0,0
FOR i = 1 to 8
  SPI WRITE 4, &b11111111,0,0,255
NEXT i
SPI WRITE 5, 0,0,0,0,0
```

On running the code you should see the Blinkt! glow bright red. If not, check the four connections are made correctly, as shown in Fig.5, and also check your code is typed exactly as shown above. To ensure you fully understand what is going on, here is an explanation of each line of code:

Line 1 Configures the SPI pins at a clock speed of 1MHz, and with 8 bits per data element

Line 2 Sends the start-of-message frame (four bytes of `00000000`)

Line 3 Forms a loop that is repeated eight times (once for each LED)

Line 4 Sets the 5-bit LED brightness to a maximum, and red intensity to full

Line 5 Repeats Line 4 eight times

Line 6 Sends the end-of-message frame (five bytes of `00000000`)

Changing colour and brightness

Assuming you have a glowing red Blinkt!, we can now explore how to change the colour, and brightness, of the LEDs. Have a go at each of the following tasks; each will require a change to Line 4 (apart from the final task):

1. Reduce the LED brightness (hint: use `&b111xxxxx` where `xxxxx` is replaced with a 5-bit binary value such as `&b11100001`). Note: a brightness value of `0` (ie, `&b11100000`) will turn the LED off
2. Change the LED colour from red to green, and set at full brightness again (remember that Line 4 sends four bytes representing: `&b111`(5-bit brightness), blue intensity, green intensity, red intensity)
3. For completeness, change the LED colour to blue
4. Now create a colour based on a mix of the RGB values – start with yellow, cyan, or magenta (hint: set any combination of two out of the three RGB intensities to 255)
5. Set colour to white (hint: requires all three RGB intensities)
6. Set to a colour of your own choice such as light purple (hint: you may want to use an online colour selector tool; eg, **www.rgbtool.com**
7. Finally, set the eight LEDs from left to right as: red, green, blue, red, green, blue, red, green (hint: comment out lines 3 and 5 to remove the loop, then add seven lines identical to Line 4 – one for each LED. Then set the first, fourth and seventh line to red, the second, fifth, and eighth to green, and the third and sixth to blue)

The above tasks will give you a clear understanding of using the SPI command to easily control RGB LEDs. Now let's put our learning into practice by building a fully featured *Mood Light*, complete with an IR remote control to change colours and functionality.

The Micromite Mood Light

Having already connected the Blinkt! module to the Micromite (via the *Development Module*), all we need to do to create the *Mood Light* is add an IR receiver.

Make the three connections as shown in Fig.5 and then download the file **MKC_MoodLight.txt** from the February 2020 page of the *PE* website. Load the program into your Micromite, and before you run it, take a quick look at the program code. I want to draw your attention to the `SUB IR_Int` (at the bottom of the program), which is called whenever the IR receiver detects an IR signal. On pressing a button on the 44-key IR transmitter, the variable `KeyCode` will be set, and its value immediately passed to `SUB IR_Int` (refer to Fig.7 to see the unique `KeyCode` value returned for each button). The main function of `SUB IR_Int` is to check which button is pressed (with `SELECT CASE KeyCode`) and to then alter the appropriate program variable(s) accordingly. Any change to any variable(s) is then immediately picked up in the main program, which will result in the required visual change to the Blinkt! LEDs. Now run the program and have a play. Below is a summary of the *Mood Light's* features, and opposite a useful reference table of the operations of each of the IR transmitter buttons.

Mood Light features

- Three modes: static (on), fade (up/down) and flash (on/off)
- Quick set a colour: red, green, blue, white, orange, pink, magenta, yellow
- Fine tune to any custom colour
- Store/recall three custom colours
- Adjust overall brightness
- Adjust fading/flashing speed
- Switch power on/off

Please feel free to add and/or change the functionality to suit your own needs! Now that you have the code and electronics working, it can be finished off by placing the Blinkt! module in an appropriate housing. You will see that the LEDs are very bright, and the ideal thing to do is add a diffuser of some kind. This can be as simple as a piece of white paper, or if you want something a little more permanent, then grab yourself an Ikea

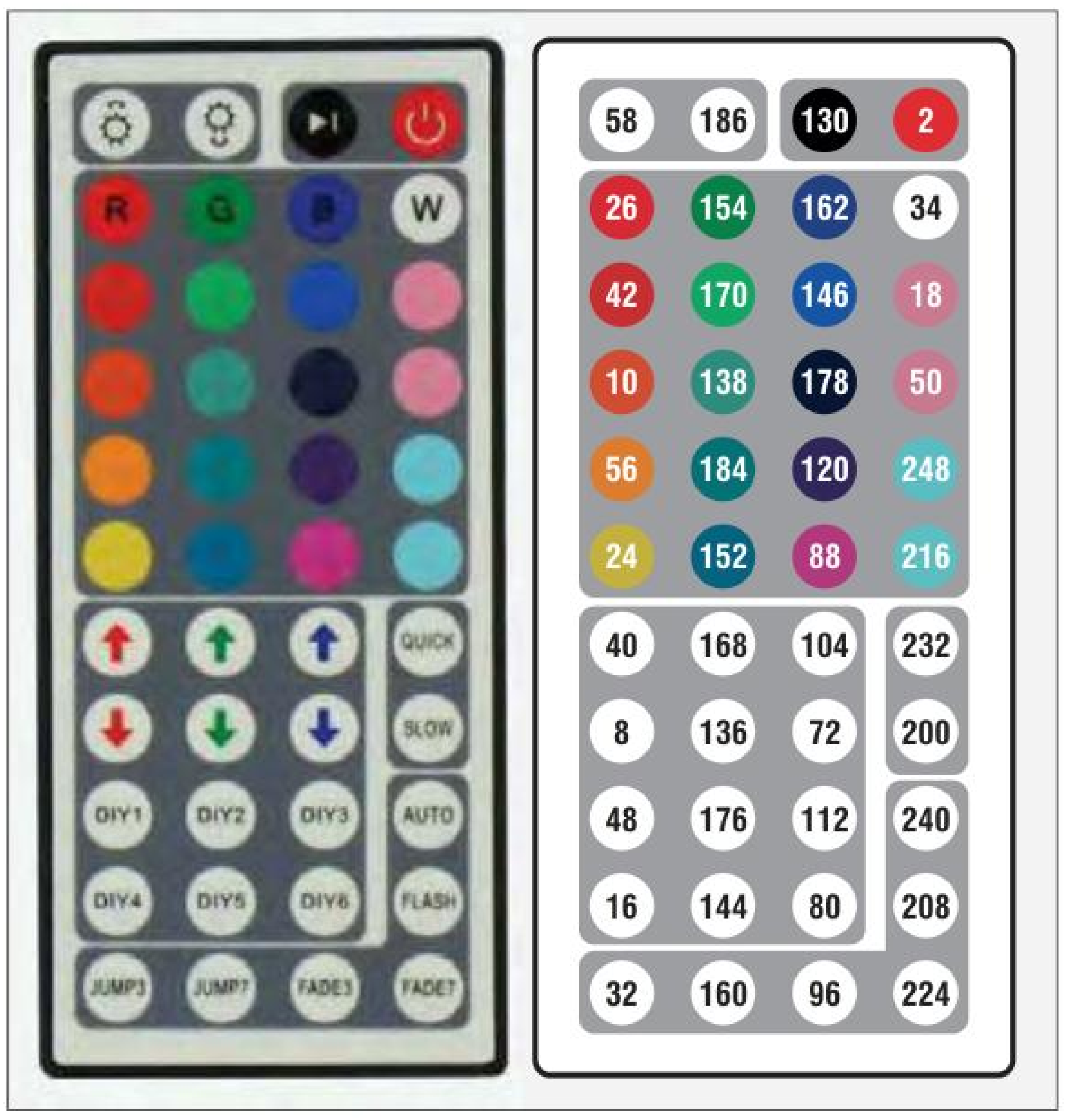


Fig.7. The 44-key IR remote control used to control the *Mood Light*. Shown on the right are the KeyCode numbers for each button, as used in the IR interrupt to determine which key has been pressed.

IR (infrared) remote control button operations

- **Increase brightness:** when in static mode, each press increases the brightness variable up to a maximum value of `31`
- **Decrease brightness:** when in static mode, each press decreases the brightness variable down to a minimum value of `1`
- **Play/pause:** when in static mode, toggles between minimum and maximum brightness
- **Power:** toggles between on and off (sets brightness variable to `0` to turn off)
- **R:** immediately switch colour variables to: `rr = 255, gg = 0, bb = 0`
- **G:** immediately switch colour variables to: `rr = 0, gg = 255, bb = 0`
- **B:** immediately switch colour variables to: `rr = 0, gg = 0, bb = 255`
- **W:** immediately switch colour variables to: `rr = 255, gg = 255, bb = 255`
- **Coloured buttons:** set appropriate values for colour variables: `rr`, `gg`, and `bb`
- **Increase red:** increases the value of the red (`rr`) variable by `5` (up to a maximum value of `255`)
- **Decrease red:** decreases the value of the red (`rr`) variable by `5` (down to a minimum value of `0`)
- **Increase green:** increases the value of the green (`gg`) variable by `5` (up to a maximum value of `255`)
- **Decrease green:** decreases the value of the green (`gg`) variable by `5` (down to a minimum value of `0`)
- **Increase blue:** increases the value of the blue (`bb`) variable by `5` (up to a maximum value of `255`)
- **Decrease blue:** decreases the value of the blue (`bb`) variable by `5` (down to a minimum value of `0`)
- **Quick:** increases the speed variable
- **Slow:** decreases the speed variable down to a minimum value of `0`
- **DIY1:** recalls the three stored custom RGB values for custom colour 1 and loads them into variables `rr`, `gg`, and `bb`
- **DIY2/DIY3:** as DIY1 (but for recalling the second or third stored custom colour)
- **DIY4:** stores the current `rr`, `bb`, and `gg` variable values into custom colour 1 memory (ie, into DIY1)
- **DIY5/DIY6:** as DIY4 (stores into either the second (DIY2), or third (DIY3) custom colour memory
- **AUTO:** not used
- **FLASH:** select flash mode
- **JUMP3/JUMP7:** select static mode
- **FADE3/FADE7:** select fade mode.

FADO table lamp (around £15) and place the 'globe' part over the Blinkt! module. This makes for a very professional looking end product, as can be seen see Fig.1.

Final thoughts for the Mood Light

This mini project has resulted in a practical gadget that you may want to keep using. To avoid tying up your *MKC* and *DM*, you could replicate the simple Micromite *Mood Light* circuit onto a piece of stripboard. All you need is a 28-pin PIC (loaded with the *Mood Light* program), a 5V PSU, a 3.3V voltage regulator, and a tantulum capacitor with a value between 10µF and 47µF (refer to the *Micromite User Manual* – Quick Start Tutorial, Basic Circuit, for connections).

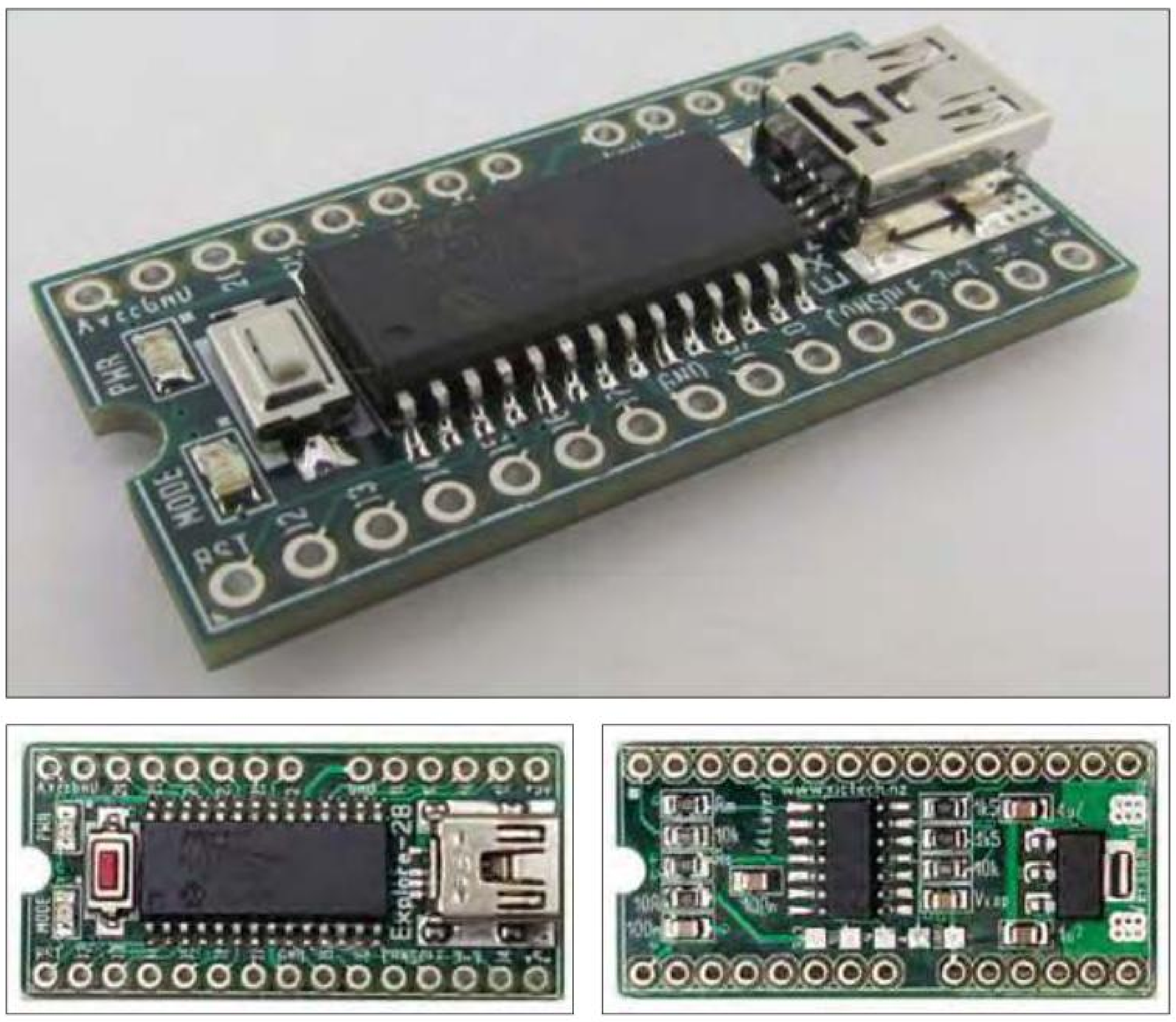


Fig.8. The Explore28 module – an SMD version of the *MKC/DM* – is ideal for building a standalone *Mood Light*. It is available fully assembled from **micromite.org** (shown here actual size in the lower two photos).

Add the IR receiver to pin 16 (and 5V power), and the Blinkt! to 5V power, and to pins 3 and 25 as shown in Fig.5. This will totally free up you *MKC* and *DM* ready for next month's article.

An alternative to building a dedicated Micromite *Mood Light* circuit is to consider using a Micromite Explore 28 module instead. This is effectively a complete *MKC* and *DM* pre-assembled onto a single, compact PCB measuring just 40mm × 20mm (see Fig.8). This tiny size is achievable because all parts are SMD. All I/O (and power) pins are brought out onto two rows of 0.1-inch header pins, making it easy to mount onto a scrap piece of strip-board and allowing you to add the Blinkt! and IR receiver. If you need any help with any of this then simply drop me an email outlining what you need to know.

Micromite Mood Light kit

A kit of parts to make the Mood Light is available from **micromite.org** – it contains a Blinkt! module, 44-key IR remote and IR receiver, as featured in this month's article.

Next month

Whenever you work through the practical topics covered in this series, or indeed whenever you use your Micromite to work on any of your own projects, you first have to position your *MKC/DM* close to your computer in order to connect them together with a USB lead. Next, you launch your preferred terminal application, point it to the relevant virtual COM port, and then you're able to interact with your 'tethered' Micromite. This is something that has hopefully become second nature to you.

Now imagine that you have a Micromite positioned somewhere remotely in your house; possibly in a hard-to-access position such as in the loft. Wouldn't it be fantastic to be able to work from your usual location, and yet somehow connect your computer to the 'remotely located' Micromite without having to relocate it? This would then allow you to interact with an un-tethered Micromite as if it were positioned right next to you (something we will eventually need for our future robot buggy project).

Next month, we'll show you how to achieve wireless (un-tethered) interaction with a remote Micromite by using a low-cost Bluetooth module.

Questions? Please email Phil at:
contactus@micromite.org

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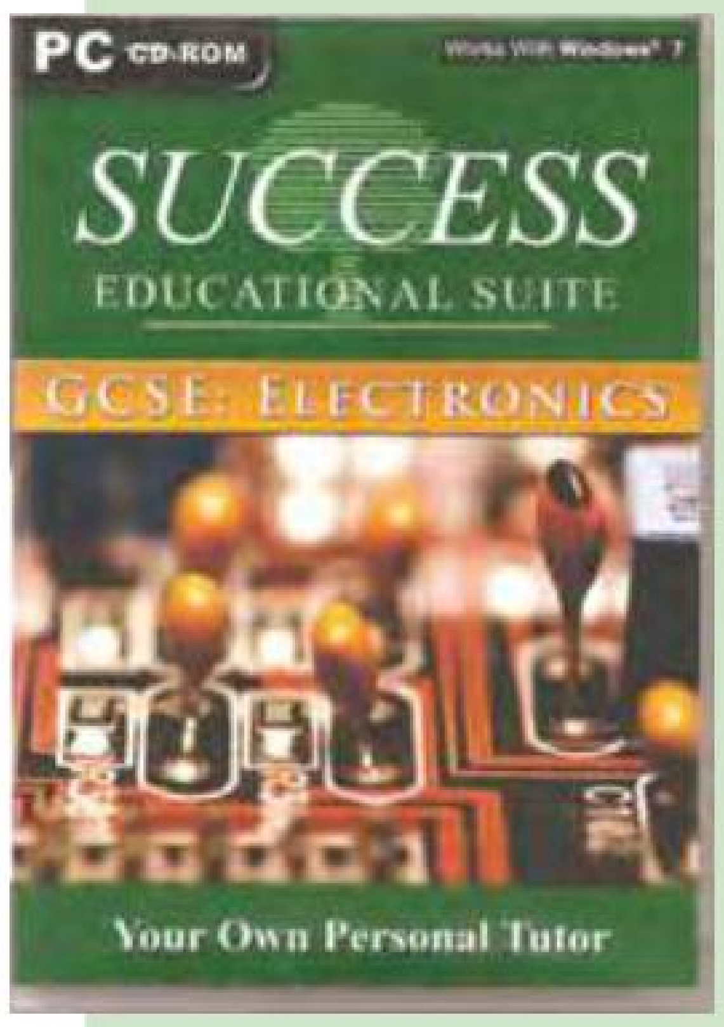

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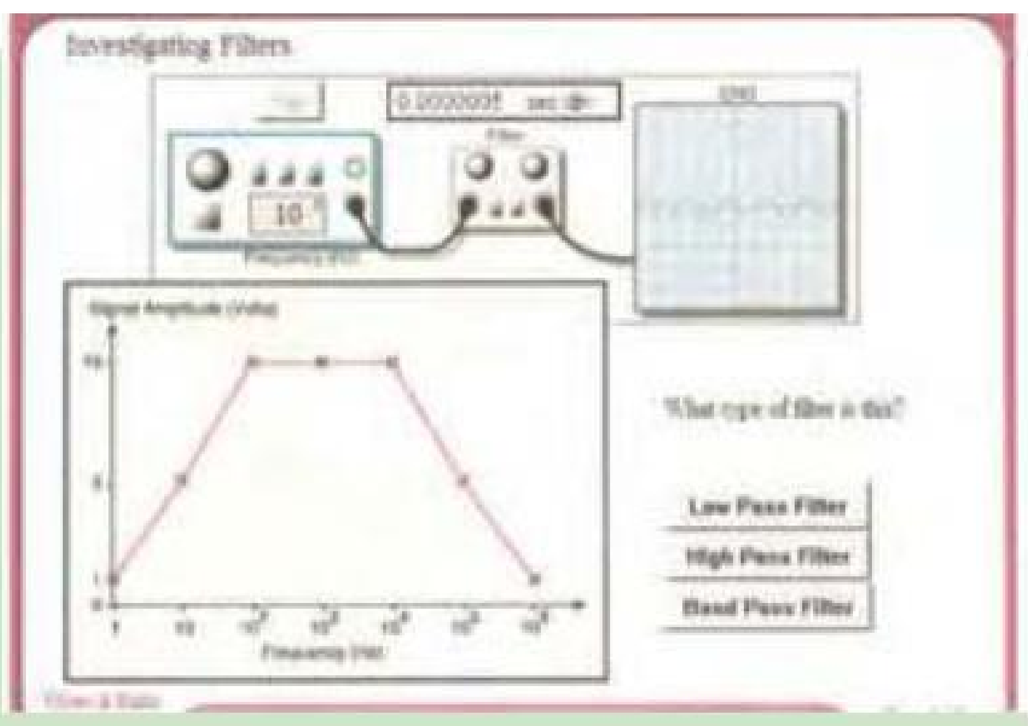

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* Circuit diagram design with component library (500 components Standard,1500 components Professional) * Virtual instruments (4 Standard, 7 professional)* On-screen animation * Interactive circuit diagram simulation * True analogue/digital simulation * Simulation of component destruction * PCB Layout * Interactive PCB layout simulation * Automatic PCB routing * Gerber export * Multi-level zoom (25% to 1000%) * Multiple undo and redo * Copy and paste to other software * Multiple document support

This software can be used with the *Jump Start* and *Teach-In 2011* series (and the *Teach-In 4* book).

Standard **£61.25** inc. VAT. Professional **£75** plus VAT.

From £49.00

TINA Design Suite V12

Analogue, Digital, Symbolic, RF, MCU and Mixed-Mode Circuit Simulation and PCB Design with TINA

FEATURED IN OUR TEACH-IN 2015 SERIES

TINA Design Suite V12 is a powerful yet affordable software package for analysing, designing and real time testing analogue, digital, MCU, and mixed electronic circuits and their PCB layouts. You can also analyse RF, communication, optoelectronic circuits, test and debug microcontroller applications.

Enter and analyse any circuit up to 100 nodes (student), or 200 with the Basic (Hobbyist) version within minutes with TINA's easy-to-use schematic editor. Enhance your schematics by adding text and graphics. Choose components from the large library containing more than 10,000 manufacturer models. Analyse your circuit through more than 20 different analysis modes or with 10 high tech virtual instruments.

Present your results in TINA's sophisticated diagram windows, on virtual instruments, or in the live interactive mode where you can even edit your circuit during operation.

Customise presentations using TINA's advanced drawing tools to control text, fonts, axes, line width, colour and layout. You can create and print documents directly inside TINA or cut and paste your results into your favourite word procesing or DTP package.

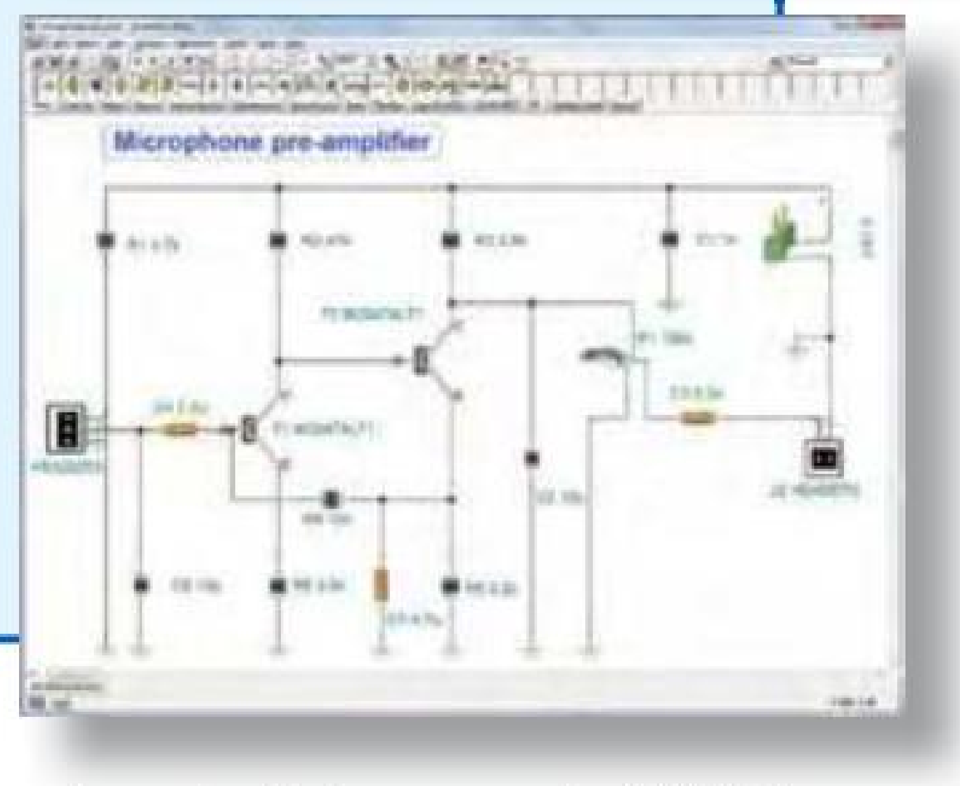
TINA includes the following Virtual Instruments: Oscilloscope, Function Generator, Multimeter, Signal Analyser/Bode Plotter, Network Analyser, Spectrum Analyser, Logic Analyser, Digital Signal Generator, XY Recorder.

3D Viewer
File View Options

This offer gives you a CD-ROM – the software will need registering (FREE) with Designsoft (TINA), details are given within the package.

Get TINA 12 Design Suite (Hobbyist) for £129 or Student V12 version for £49

Prices include VAT and UK postage



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PICmicro TUTORIALS AND PROGRAMMING

HARDWARE

PICmicro Multiprogrammer Board and Development Board

Suitable for use with the three software packages listed below

This flexible PICmicro microcontroller programmer board and combination board allows students and professional engineers to learn how to program PICmicro microcontrollers as well as program a range of 8, 18, 28 and 40 pin devices from the 12, 16 and 18 series PICmicro ranges. For those who want to learn, choose one or all of the packages below to use with the hardware.

- Makes it easier to develop PICmicro projects
- Supports low cost Flash-programmable PICmicro devices
- Fully featured integrated displays – 16 individual LEDs, quad 7-segment display and alphanumeric LCD display
- Supports PICmicro microcontrollers with A/D converters
- Fully protected expansion bus for project work
- USB programmable
- Compatible with the E-blocks range of accessories

£159.99 including VAT and postage (worldwide)

SOFTWARE

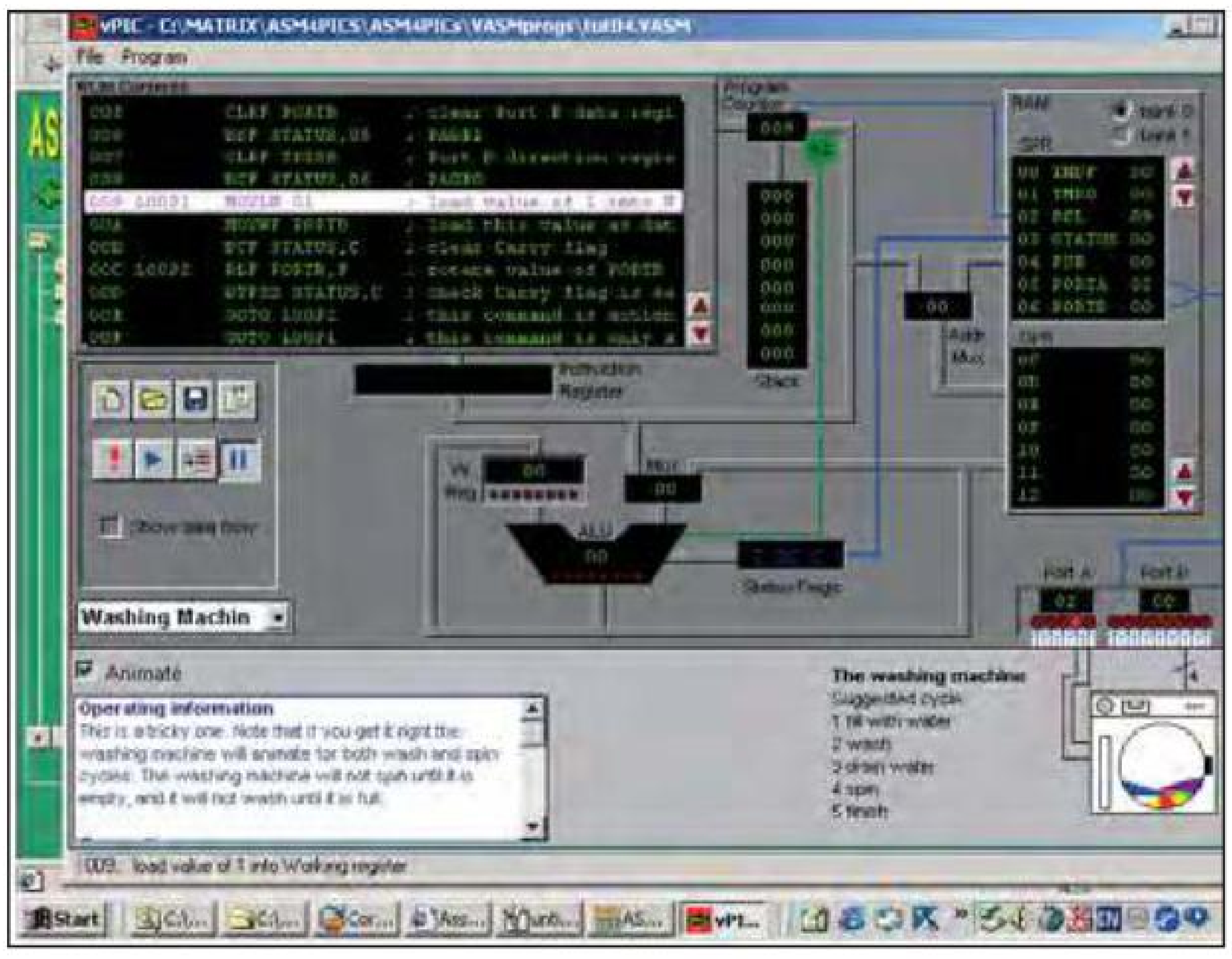
ASSEMBLY FOR PICmicro V7

(Formerly PICtutor)

Assembly for PICmicro microcontrollers V7.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84, 16F88 and 16F877a PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

- Comprehensive instruction through 45 tutorial sections
- Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator
- Tests, exercises and projects covering a wide range of PICmicro MCU applications
- Includes MPLAB assembler
- Visual representation of a PICmicro showing architecture and functions
- Expert system for code entry helps first time users
- Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.)
- Imports MPASM files.



Operating information
This is a tricky one. Note that if you get it right the washing machine will animate for both wash and spin cycles. The washing machine will not spin until it is empty, and it will not wash until it is full.

The washing machine
Suggested cycle
1 fill with water
2 wash
3 drain water
4 spin
5 finish

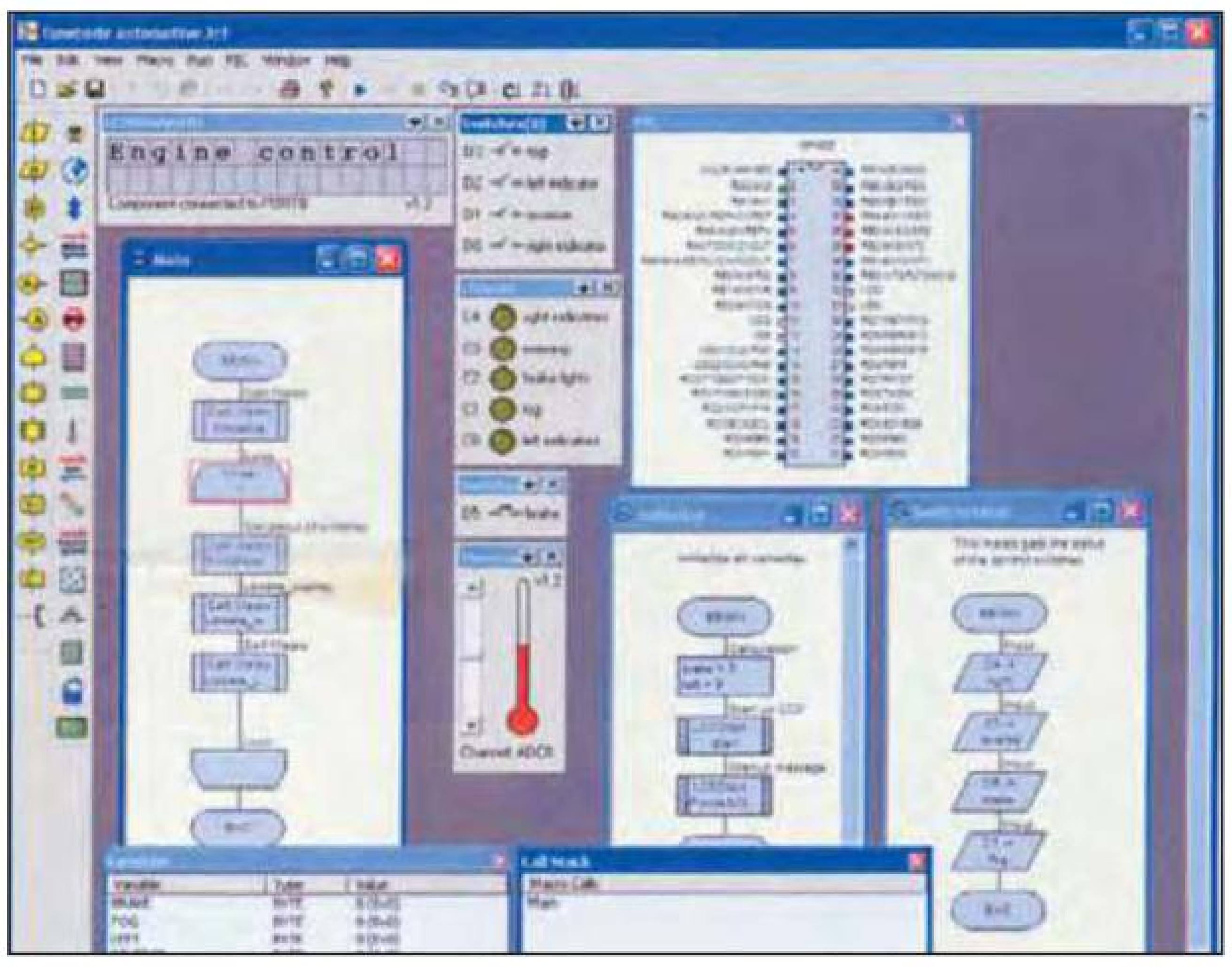
009: load value of 1 into Working register

FLOWCODE FOR PICmicro V8

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
- Allows complex PICmicro applications to be designed quickly
- Uses international standard flow chart symbols
- Full on-screen simulation allows debugging and speeds up the development process.
- Facilitates learning via a full suite of demonstration tutorials
- Produces code for a wide range of devices
- 16-bit arithmetic strings and string manipulation
- Pulse width modulation
- I2C.

Please note: Due to popular demand, Flowcode is now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you.



PRICES

Prices for each of the CD-ROMs above are:

(Order form on next page)

(UK and EU customers add VAT to 'plus VAT' prices)

Single License	**£99**	**plus VAT**
Site Licence	**£499**	**plus VAT**
Flowcode **(choose PIC-8b, PIC-16b, PIC-32b, AVR/Arduino,ARM)**	**Contact us for pricing**	

ELECTRONICS TEACH-IN 2

ELECTRONICS TEACH-IN 2 CD-ROM
USING PIC MICROCONTROLLERS A PRACTICAL INTRODUCTION

This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

CD-ROM **Order code ETI2 CD-ROM** **£9.50**

ELECTRONICS TEACH-IN 3

ELECTRONICS TEACH-IN 3 CD-ROM

The three sections of this CD-ROM cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on circuit design problems – from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

The CD-ROM also contains the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial).

The Teach-In 1 series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC.

CD-ROM **Order code ETI3 CD-ROM** **£8.50**

ELECTRONICS TEACH-IN 4

ELECTRONICS TEACH-IN 4 CD-ROM
A BROAD-BASED INTRODUCTION TO ELECTRONICS.

The Teach-In 4 CD-ROM covers three of the most important electronics units that are currently studied in many schools and colleges. These include, Edexcel BTEC level 2 awards and the electronics units of the Diploma in Engineering, Level 2.

The CD-ROM also contains the full Modern Electronics Manual, worth £29.95. The Manual contains over 800 pages of electronics theory, projects, data, assembly instructions and web links.

A package of exceptional value that will appeal to all those interested in learning about electronics or brushing up on their theory, be they hobbyists, students or professionals.

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160 Pages **Order code ETI5** **£8.99**

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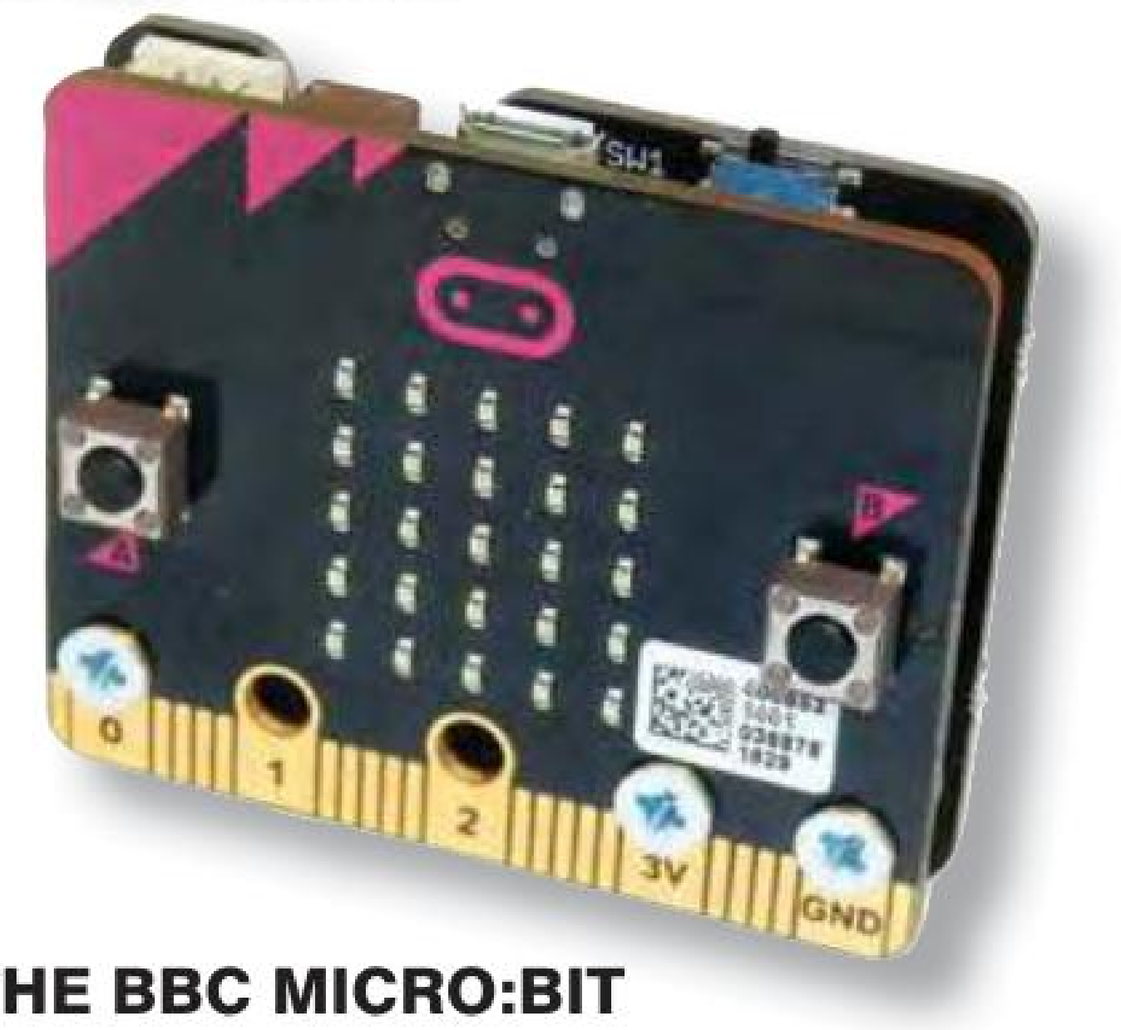
Teach-In 2017

Introducing the BBC micro:bit



IN FULL COLOUR
For Beginners of Any Age
Python Coding on the BBC micro:bit
Jim Gatenby

PYTHON CODING ON THE BBC MICRO:BIT

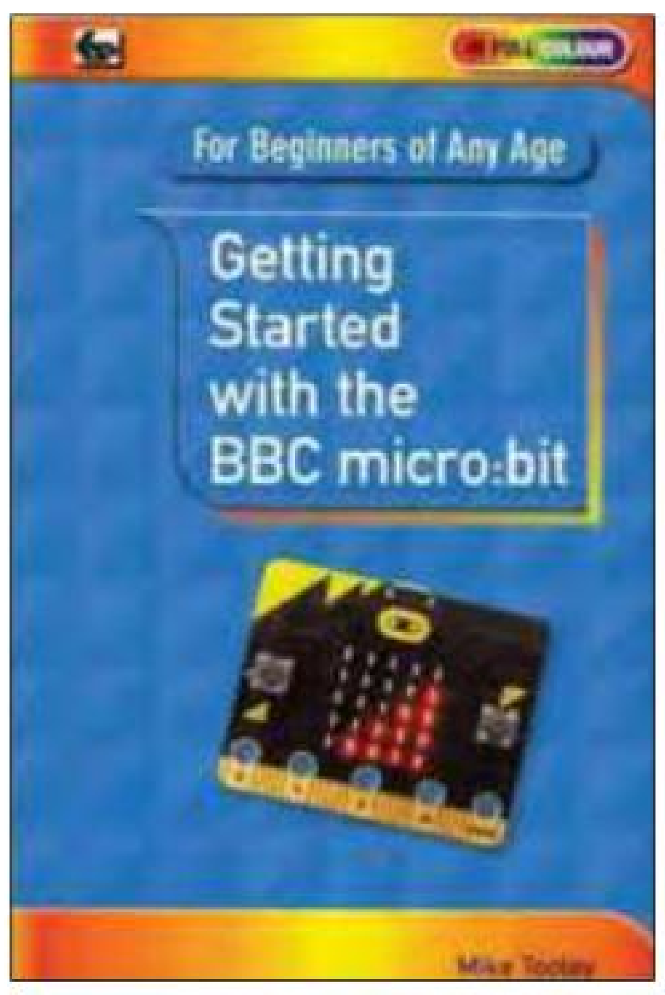
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: main features of the BBC micro:bit including a simulation in a web browser screen; various levels of programming languages; Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; scrolling messages, creating and animating images on the micro:bit's LEDs; playing and creating music, sounds and synthesized speech; using the on-board accelerometer to detect movement of the micro:bit on three axes; glossary of computing terms.

This book is written using plain English, avoids technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** £7.99



GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages **Order code BBC MBIT** £7.99

THEORY AND REFERENCE

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STARTING ELECTRONICS – 4th Ed **Keith Brindley**	*296 pages*	**Order code ELSEV100**	£18.99
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FOR A FULL DESCRIPTION OF THESE BOOKS AND CD-ROMS SEE THE SHOP ON OUR WEBSITE

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MICROPROCESSORS

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MICROCONTROLLER COOKBOOK **Mike James**	*240 pages*	**Order code NE26**	£36.99

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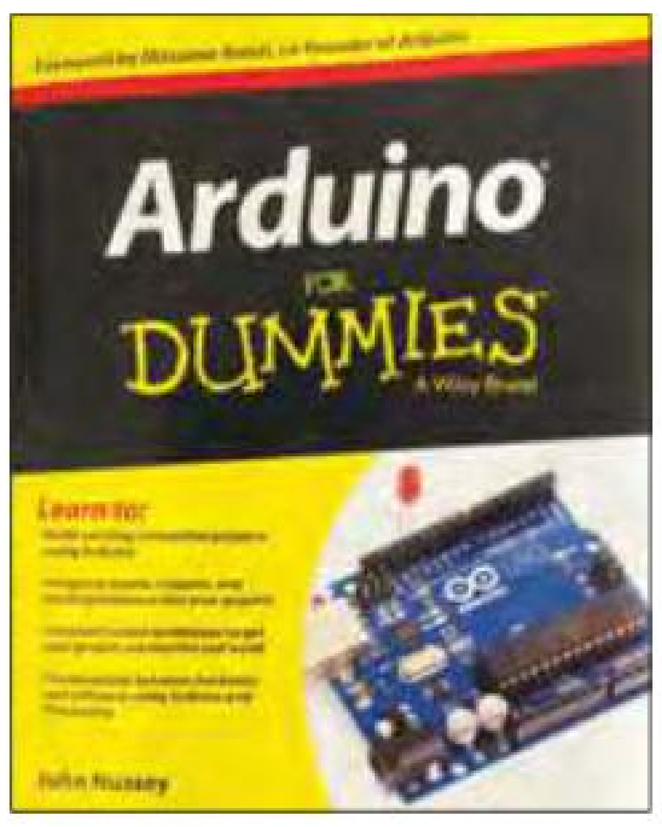
ARDUINO

Teach-In 2016

See opposite for our popular introduction to the Arduino



ARDUINO FOR DUMMIES
John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

- **Learn by doing** – start building circuits and programming your Arduino with a few easy examples – right away!
- **Easy does it** – work through Arduino sketches line by line, and learn how they work and how to write your own.
- **Solder on!** – don't know a soldering iron from a curling iron? No problem! You'll learn the basics and be prototyping in no time.
- **Kitted out** – discover new and interesting hardware to turn your Arduino into anything from a mobile phone to a Geiger counter.
- **Become an Arduino savant** – find out about functions, arrays, libraries, shields and other tools that let you take your Arduino project to the next level
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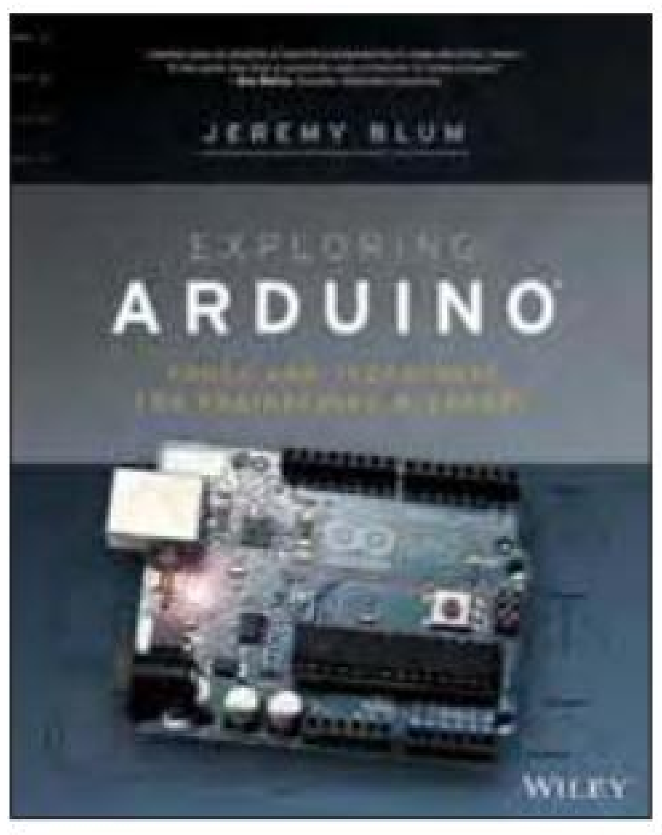
438 Pages **Order code ARDDUM01** **£19.99**



EXPLORING ARDUINO
Jeremy Blum

Arduino can take you anywhere. This book is the roadmap.

Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction, this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

- **Explore** the features of commonly used Arduino boards
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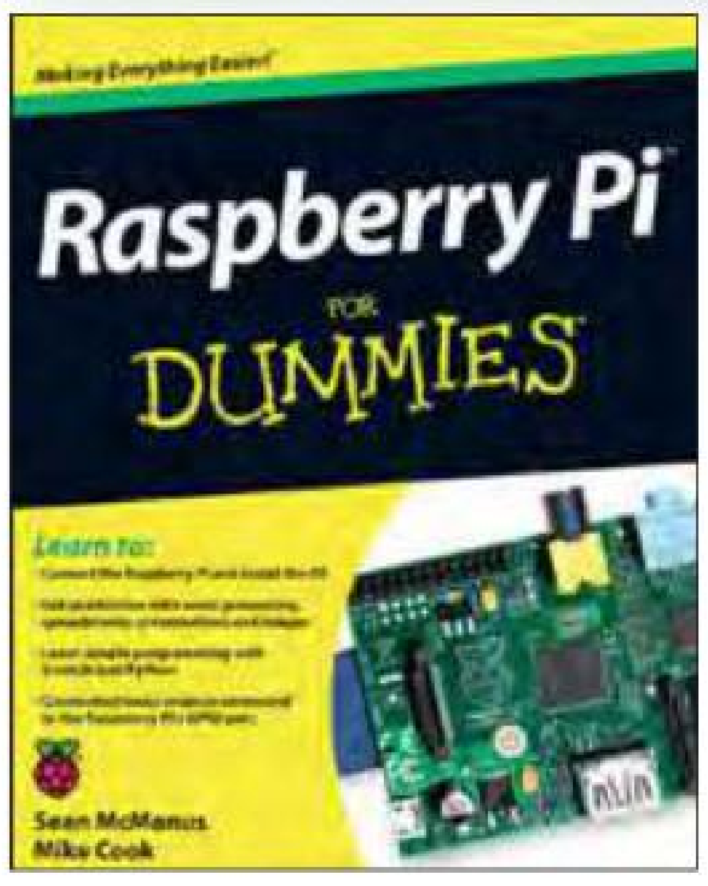
RASPBERRY PI



RASPBERRY Pi FOR DUMMIES
Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more!

Open this book and find:
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ONLY AVAILABLE ON CD-ROM

ELECTRONICS TEACH-IN 6
A COMPREHENSIVE GUIDE TO RASPBERRY Pi

Mike & Richard Tooley

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low-cost computer that has taken the education and computing world by storm.

This latest book in our Teach-In series will appeal to electronic enthusiasts and computer buffs wanting to get to grips with the Raspberry Pi.

Anyone considering what to do with their Pi, or maybe they have an idea for a project but don't know how to turn it into reality, will find Teach-In 6 invaluable. It covers: Programming, Hardware, Communications, Pi Projects, Pi Class, Python Quickstart, Pi World, and Home Baking.

The CD-ROM also contains all the necessary software for the series so that readers can get started quickly and easily with the projects and ideas covered.

160 Pages **Order code ETI6** **£8.99**

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Mike & Richard Tooley

Teach-In 7 is a complete introduction to the design of analogue electronic circuits. Ideal for everyone interested in electronics as a hobby and for those studying technology at schools and colleges. Supplied with a free cover-mounted CD-ROM containing all the circuit software for the course, plus demo CAD software for use with the Teach-In series

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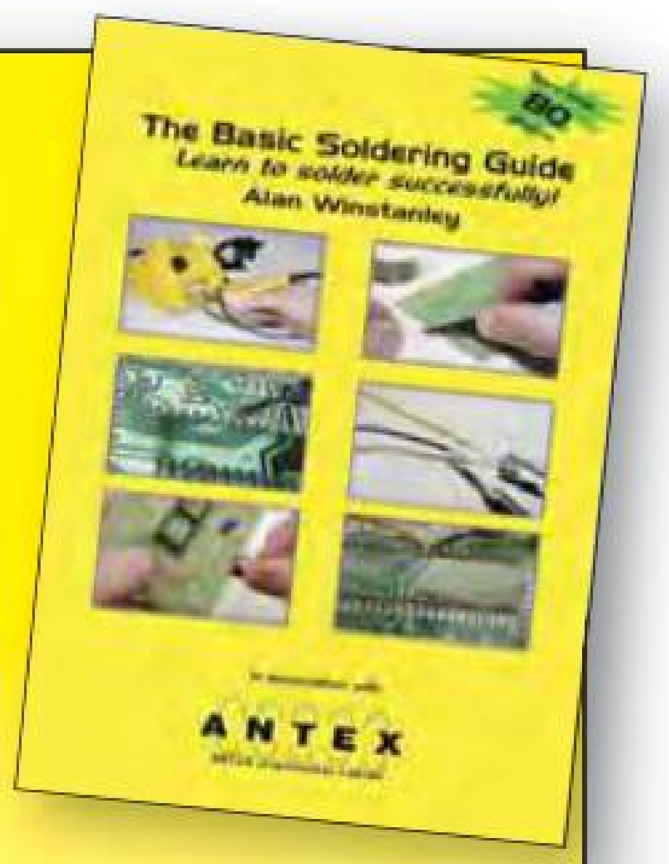
THE BASIC SOLDERING GUIDE



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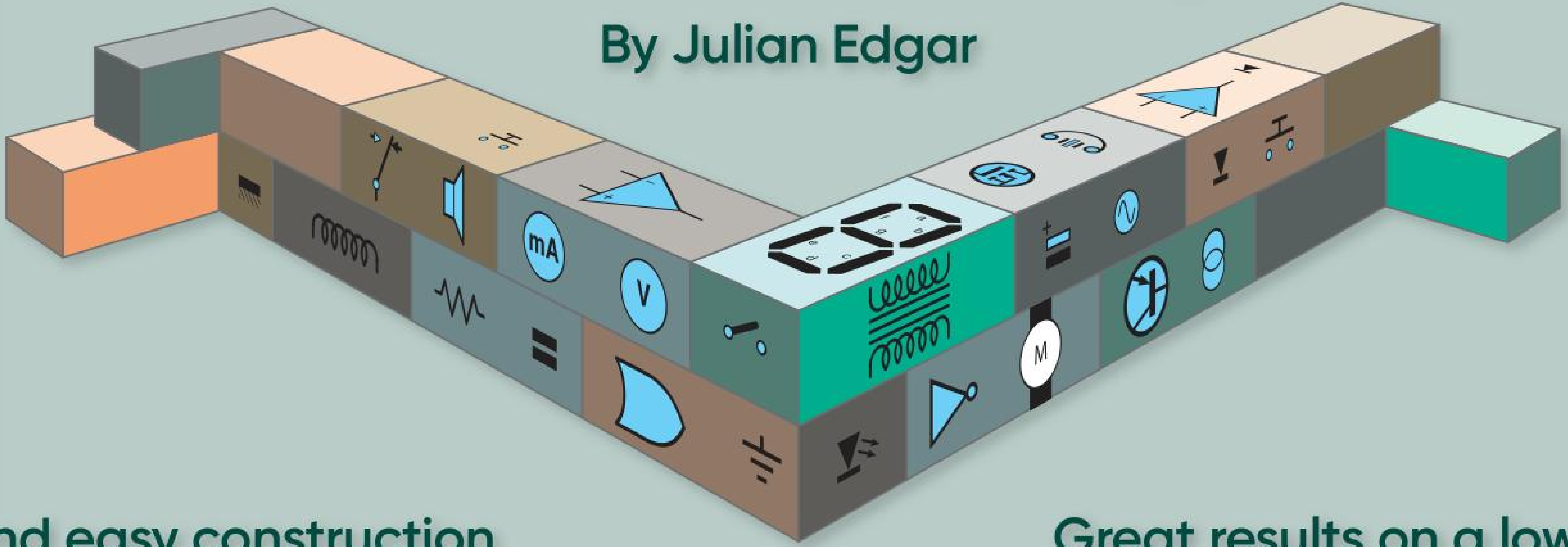
By Julian Edgar



Quick and easy construction

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Re-purposing an old camera battery

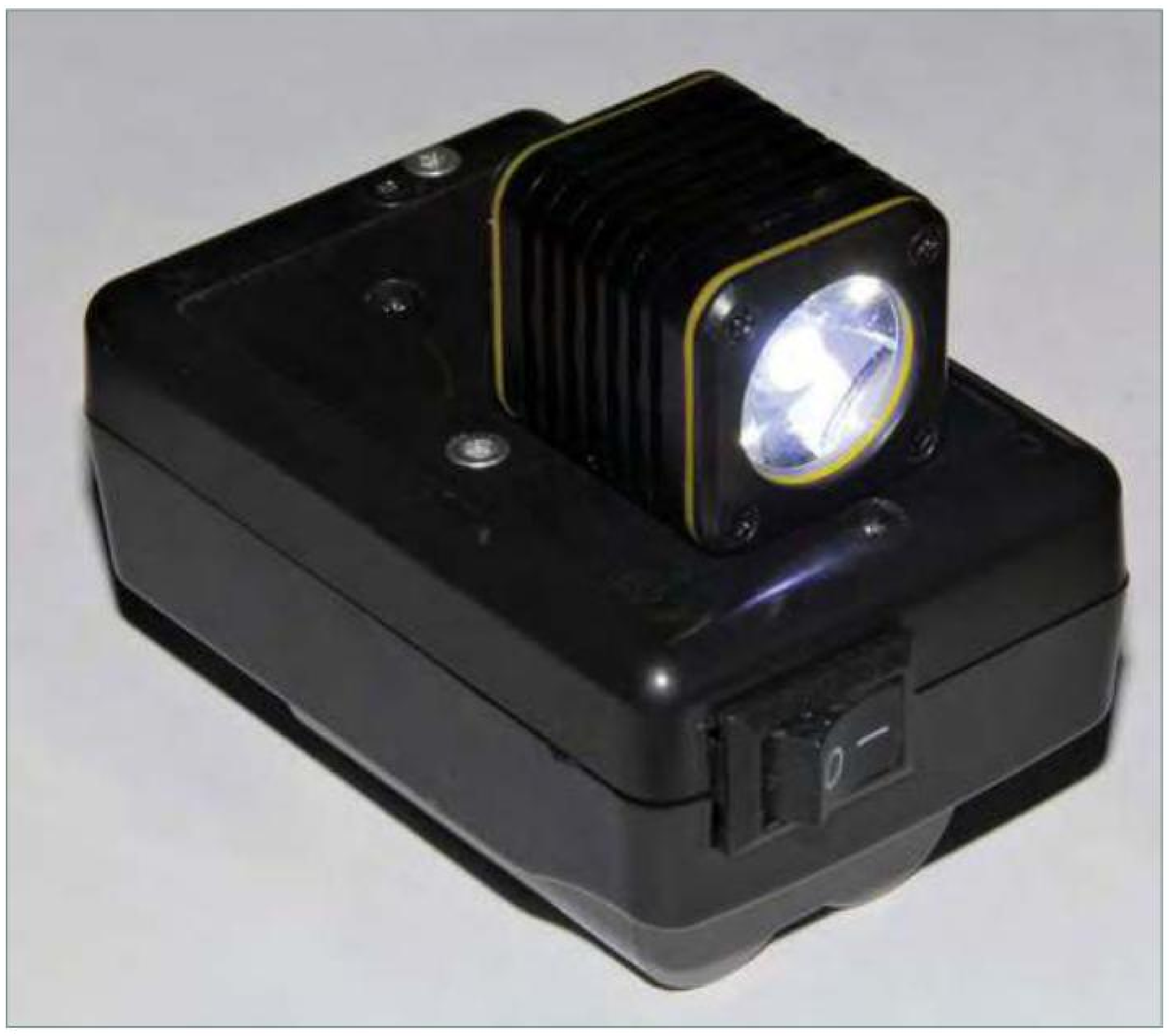

Fig.1. An old Li-ion camera battery drives this powerful LED torch. Batteries of this type may not have enough capacity to run a camera, but they still have plenty of life left for other purposes.

Here's a project that will be ideal for some people – and not at all ideal for others! It depends on what you have already sitting on the shelf. But first, a bit of background.

For many years I've used a Nikon D200 SLR camera. It uses a separately rechargeable Li-ion battery. That is, when the battery needs to be charged, you remove the battery from the camera and clip it to a mains-powered charger – a small box.

One in camera, one ready for use

I've always used two batteries (one being charged and one being used) and they've lasted extraordinarily well. However, all good things come to an end, and I noticed that the batteries were not providing as many camera shots as they once did. I looked up the price of new Nikon batteries – incredibly high – and then settled on two non-genuine batteries from a reputable supplier. That left me with the two original Nikon batteries.

Ostensibly, the original Nikon batteries were 'worn out' – but were they? I did some testing and it seemed to me that they had plenty of life left. Not enough to power a camera, but enough for other applications. However, electrically connecting to the batteries is difficult as they use flat terminals that engage with spring strips when placed in either the camera or on the charger. So the first step was to figure out some effective battery connections.

Incredibly, a replacement charger was available on eBay for only about £3, including post. Remove the charging circuitry, and you have an elegant way of connecting to the battery – and as a bonus, you also end up with a small enclosure.

The voltage of the Nikon battery is nominally 7.4V – an odd voltage in these days of USB-standard 5V for so many devices. However, buck converter modules are available at very low prices, and these can easily be set to give a constant 5V output. (And they're also much more efficient than using a 5V linear regulator.) I had a buck converter in my parts drawers, so that was good! I also happened to have on the shelf a very powerful 5V miniature LED spotlight that the battery could power.

When the charger arrived, it was only a matter of minutes to open it up, remove the charging electronics and wire the battery leads to the buck converter (set for a 5V output) and then to the LED spotlight. At this stage I'd spent only £3 – I was just curious as to how effective the project would be. If it turned out that the original camera batteries were in fact no good, I could reinstall the charger electronics and have a spare charger for my camera.

The LED spotlight has three in-built power levels (1W, 3W and 6W). I set the light to its lowest level (still very bright), ensured the battery was fully charged and then clipped it into place. On came the light, and I set a timer running. An hour later, the light was as bright as ever, and the battery voltage was still around 6.8V. That showed that the approach was viable, so I built the final unit.

I added an on/off switch (that nicely fills the rectangular opening where the original mains power cord plugged in) and installed a small battery voltage indicator board. This has a dual colour LED that changes from green to red when battery voltage falls below an adjustable level. In my application, where I was working right on the edge of the lowest voltage at which this module will work, the LED actually switches off at the critical voltage. That means it is still fine as an indicator – green

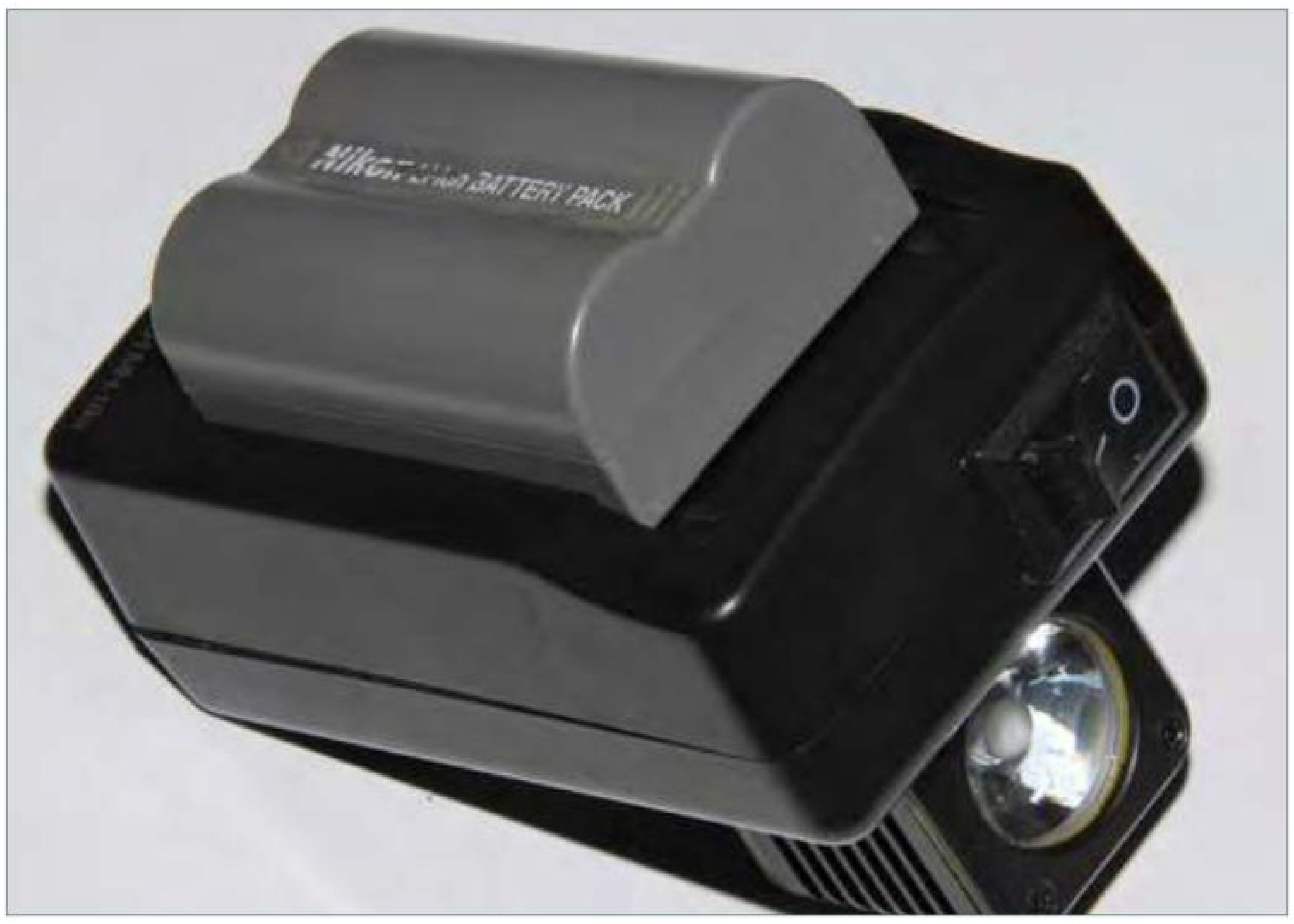

Fig.2. The body of the torch is made from a gutted charger that suits the battery pack. Taking this approach makes it easy to electrically connect to the battery. The on/off switch fills the opening that previously housed the mains power connection.

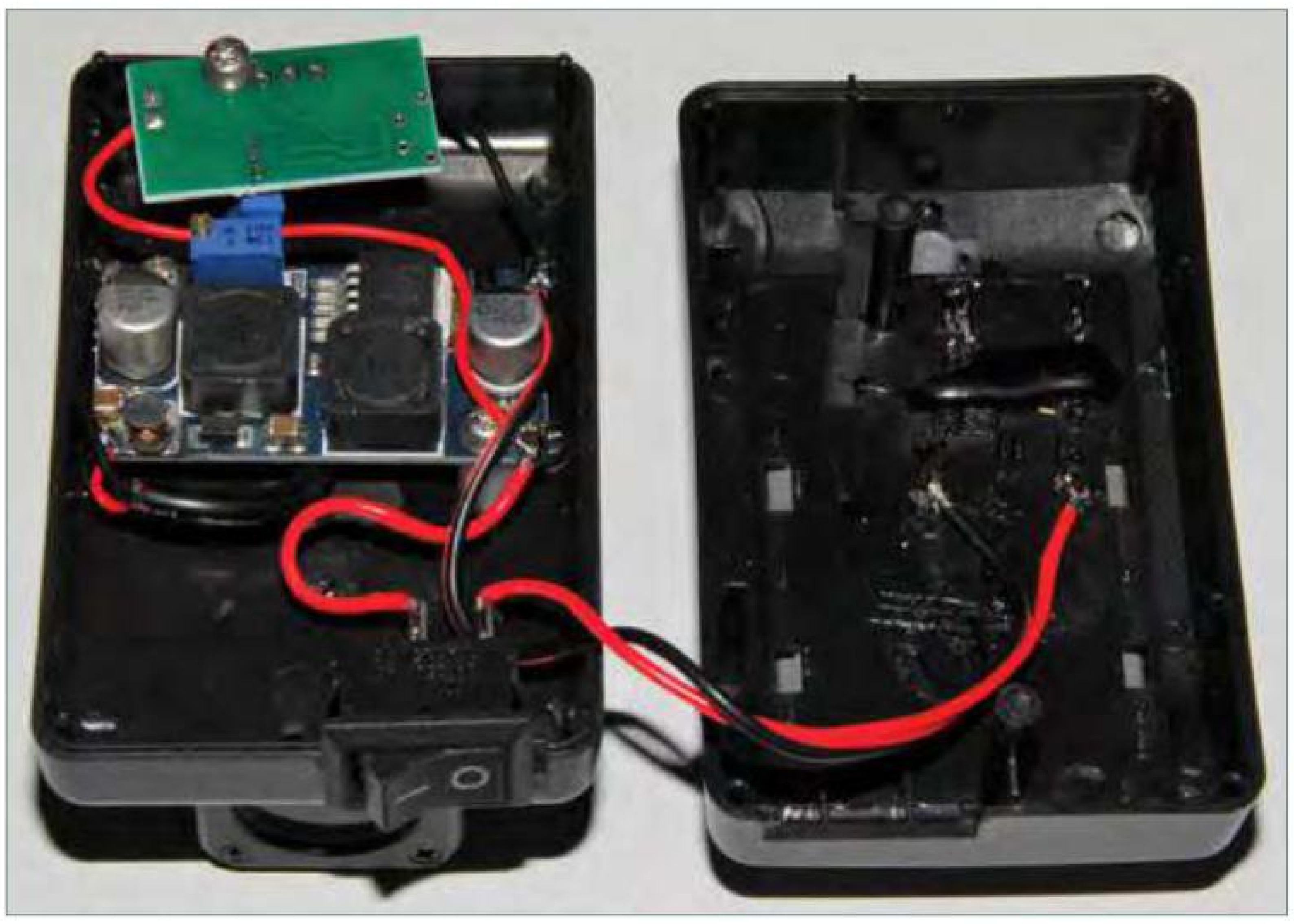

Fig.3. Inside the charger body are the new electronics. The main board is a buck converter to reduce battery voltage to 5V, and the upper board indicates via a LED when the battery needs to be unclipped and charged.

is good, white (off) means that the battery needs to be unclipped and charged.

Requirements

So what do you need to make this a worthwhile project?

- A high quality Li-ion camera battery that still has plenty of life left but isn't quite good enough for the camera
- A charger for the battery
- A way of easily connecting to the battery – eg, through the purchase of a second charger that is then gutted with just the battery connections and enclosure used
- A buck (or boost) converter to provide the voltage output you want (eg, 5V)
- An output device: an LED light, or USB socket if you want to provide a general-purpose 5V supply.

Obviously, you can buy USB powerbanks very cheaply, but in my experience, good ones are still much more expensive than this project. (Cheap ones that last only a few weeks of use cost nearly nothing, but they fail just when you really need them!)

Years of extra use!

Whenever I use my LED spotlight it's a real pleasure to see a battery that would otherwise have been discarded still doing good and useful work.

Teach-In 8 CD-ROM Exploring the Arduino

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Next Month – in the March issue

Audio DSP – Part 3

Next month, we test the *DSP Crossover* modules, connect them together and power the whole unit up. Once it has been tested and assembled into its case, you can then set it up before linking it between your preamplifier and power amplifier(s).

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Steam Train Whistle

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Bluetooth-Micromite operation

In next month's *Make it with Micromite*, we'll show you how to achieve wireless (un-tethered) interaction with a remote Micromite by using a low-cost Bluetooth module.

PLUS!

All your favourite regular columns from *Audio Out, Cool Beans and Circuit Surgery,* to *Electronic Building Blocks*, *PIC n' Mix* and *Net Work*.

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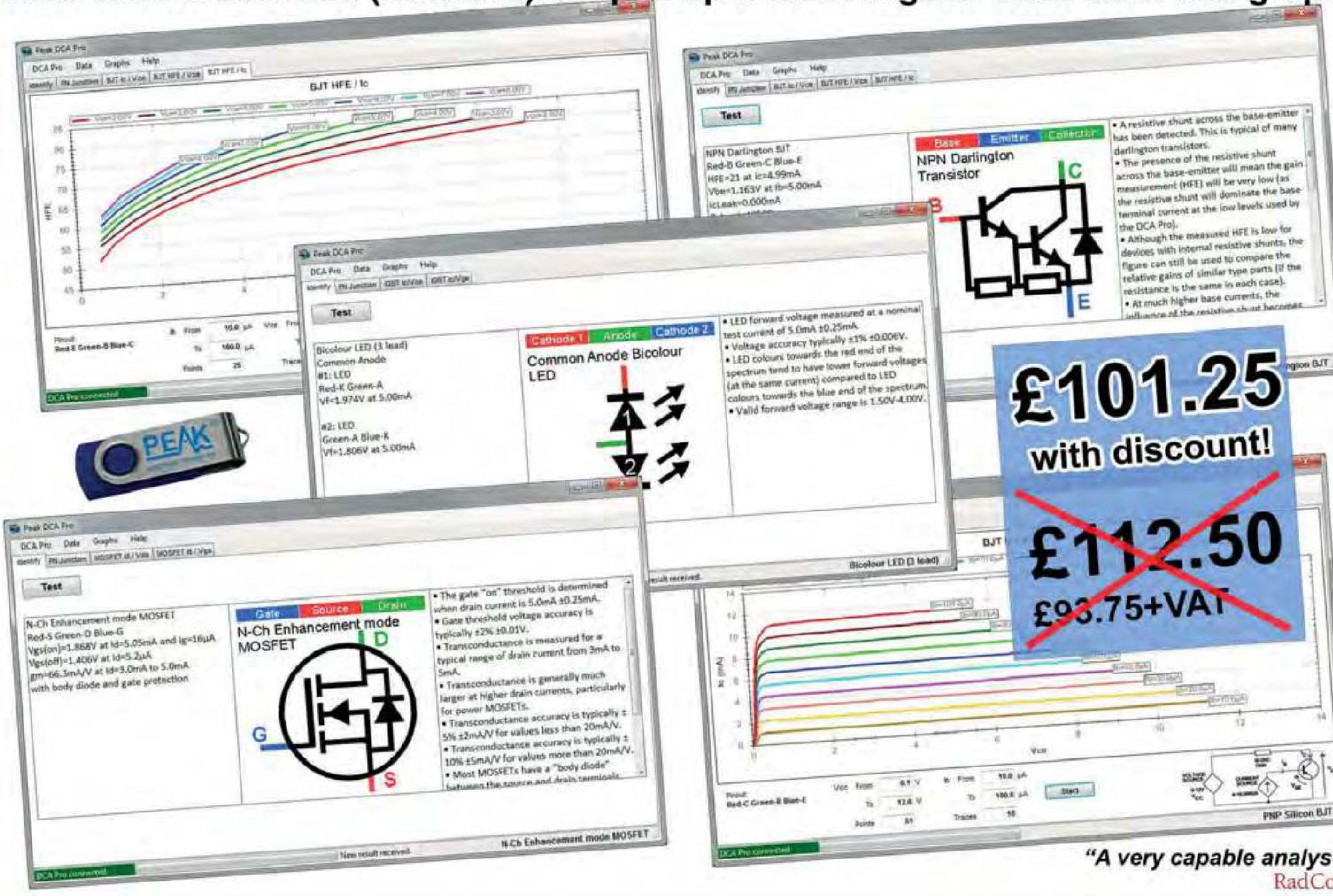
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Anode
Cathode 2
Common Anode Bicolour LED
Gate
Source
Drain
N-Ch Enhancement mode MOSFET
G
D
S
PEAK
DCA Pro connected
New result received
Bicolour LED (3 lead)
N-Ch Enhancement mode MOSFET
PNP Silicon BJT

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Common Anode
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Red-K Green-A
Vf=1.974V at 5.00mA

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Green-A Blue-K
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